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Biological processes which occur in facultative aerated lagoons are reviewed and the performance of cold climate aerated lagoons is examined. Winter and summer performance is compared, and general criteria for the design of cold climate lagoons is presented. Sample calculations for predicting the performance of aerated lagoons are also shown. These calculations are based on the complete mix equation for aerated lagoon design and on the results of the data analysis presented in this report. The information presented indicates that lagoons can be designed or upgraded to meet P.L. 92-500 secondary standards. This may be done by increasing the number of cells in series, by reducing short circuiting and through the use of a polishing pond. It is shown that additional cells in series, for a given detention time, will increase the BOD removal efficiency of a lagoon.

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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere. CERL's Arctic Environmental Research Station conducts research on the effects of pollutants on Arctic and sub-Arctic freshwater, marine water and terrestrial system; and develops and demonstrates pollution control technology for cold-climate regions.

This report examines the performance of cold climate aerated lagoons and presents the results of lagoon studies conducted by the Arctic Environmental Research Station.

James McCarty
Acting Director, CERL

ABSTRACT

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This report is a summary of work on aerated lagoons which was initiated by Mr. Sidney E. Clark, first Waste Treatment Research Director, Arctic Environmental Research Station (AERS). His contribution is gratefully acknowledged.

Much of the work covered in this report was accomplished with the cooperation of the U. S. Air Force and U. S. Army. Through an interagency agreement with the Alaskan Air Command, the AERS constructed and operated, with Air Force assistance, an experimental facility at Eielson Air Force Base, Alaska. Much of the information contained in this report was obtained from an aerated lagoon constructed as part of the experimental facility. Another interagency agreement with the U. S. Army, Alaska, allowed the AERS to modify a full scale aerated lagoon at Ft. Greely, Alaska which also resulted in a significant amount of the information included in this report. Additional information was obtained from a lagoon at Northway, Alaska through the cooperation of the Federal Aviation Administration.

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INTRODUCTION

Waste treatment lagoons have become increasingly popular in the United States and Canada. In spite of this fact, sufficient information has not been available to establish sound design criteria, particularly for cold climate regions. As was stated in a recent state-of-the-art review (McKinney, et al. 1971), "Only in a few instances has there been development of basic data sufficient to produce sound criteria. While there has been a large number of studies in waste treatment lagoons, most of these studies have been fragmented and lacking in sufficient depth to have real meaning. If we are to continue to design and construct waste treatment lagoons, it is important that we have proper design criteria that will result in the production of the desired effluent quality".

Aerated lagoons have many advantages which make them very desirable for use in Alaska, especially since the standards for lagoons have been revised. The new standards allow for higher effluent suspended solids during summer months to accommodate algae growth. Among the advantages of lagoons are low operating and maintenance requirements, resistance to upsets and built-in sludge digestion and storage capabilities. A major disadvantage is the large land area requirement.

CONCLUSIONS & RECOMMENDATIONS

The performance of lagoons in northern climates has been evaluated. Methods for predicting the performance of aerated lagoons in northern climates have been derived from pilot plant and full scale operating data. Conclusions can be drawn as follows:

1. Lagoon systems which can meet secondary standards can be designed for northern climates. Raising the allowable summertime effluent suspended solids should make the aerated lagoon a more attractive alternative.
2. The following considerations should be kept in mind in designing or upgrading lagoon systems (see the section on lagoon design and upgrading):
   a. Special attention should be given to the possibility of short-circuiting within the cells. Strategic placement of baffles and aerators can reduce this problem.
   b. Lagoon cells should be provided in series to reduce short-circuiting due to complete mix conditions. Cells in series also result in greater reductions in bacteria and algae for a given detention time.

c. Heavy aeration should be provided at the lagoon influent in order to maintain influent solids in suspension. This will increase the rate of conversion of dissolved and colloidal solids to suspended solids, which can be removed by sedimentation. Also, the solids will undergo some aerobic decomposition and help prevent buildup of sludge under septic conditions which can retard digestion.

d. Adequate sludge storage (1500 liters/1000 m^3 of domestic sewage) should be provided in the first sections of the lagoon so that aerobic oxidation of summer sludge digestion byproducts will occur in succeeding cells before the effluent is discharged.

e. A polishing or maturation pond should be provided as the last cell in series.

f. The limited data on disinfection indicates that summer algae production results in disinfection rates similar to those during cold temperature operations in winter.

The performance of coarse bubble diffusers in aerated lagoons has been evaluated. The coarse bubble diffuser can provide an attractive alternative to the fine bubble diffuser for aeration in lagoons. Conclusions may be reached as follows:

1. Fine bubble diffusers are more efficient in oxygen transfer than coarse bubble diffusers, however, they are not necessarily more economical.

2. Power requirements in terms of lb. O_2 transferred/hp-hr may be higher for fine bubble diffusers because of the restricted openings which require higher blower discharge pressures.
3. Maintenance requirements for fine bubble diffusers are higher because of clogging which requires periodic cleaning. The clogging also results in higher compressor maintenance due to increased discharged pressures.
4. Oxygenation efficiencies published in the literature or supplied by coarse bubble diffuser manufacturers may be used for aerated lagoon design.
5. In areas where ice fog is a problem, a larger number of diffusers (less air flow per diffuser) at an increased spacing would minimize the generation of ice fog without significantly affecting oxygenation efficiencies.
6. Excluding transfer efficiency, a ratio of 1.5 g O_2/g BOD_5 removed was found adequate for sizing aeration equipment for cold climate aerated lagoons.

BACKGROUND

LAGOON STUDIES IN ALASKA

Pohl (1967) presented a theoretical discussion of cold climate aerated lagoons. Clark et al., (1970) provided an extensive summary of lagoon operations under cold climate conditions and Grainge et al., (1972) reviewed Canadian experiences with lagoons. Design criteria for arctic and subarctic aerated lagoons has been presented by Reid (1970, 1975).

One of the first aerated lagoons in Alaska was an experimental facility located at the Eielson Air Force Base near Fairbanks and operated by the Arctic Health Research Center of the U.S. Public Health Services in 1964 and 1965 (Reid, 1970). This lagoon established the feasibility of utilizing aerated lagoons in the subarctic. Late in 1967, the Alaskan Air Command and the Arctic Environmental Research Station entered into an agreement to construct and operate a field research facility that included an aerated lagoon pilot plant at Eielson Air Force Base. Also, during this period, Pohl (1967) presented an approach for the design of aerated lagoons. Based on the information established from these initial efforts and the Alaska State Water Quality

Standards in effect at that time, a number of aerated lagoons were constructed in Alaska, particularly for remote government installations. These lagoons have been successful for the most part but have not been without problems and were generally unable to meet the 30/30 secondary standards required by Public Law 92-500.

The secondary standards for lagoons have been revised to allow for higher effluent suspended solids (SS) levels during summer months (Federal Register, 1977). The Alaska Operations Office of the Environmental Protection Agency has submitted a value of 70 mg/l as the SS limit for summer operation (Dan Crevenston, Personal Communication 1977). The effluent must also appear green for this high value to apply. The standards for BOD effluent levels remain the same. The 70 mg/l value is base on actual lagoon operating data and applies to the state of Alaska only, since each state is required to determine a value individually. This approach will allow lagoons to be designed based on BOD requirements but eliminates the need for special equipment or operations for algae removal.

FACULTATIVE AERATED LAGOONS

The incomplete mix or facultative aerated lagoon is designed with sufficient aeration capacity to ensure uniform oxygen concentration throughout the liquid but insufficient capacity to maintain solids in suspension. As raw waste enters the lagoon, the settleable solids are deposited while the soluble and colloidal organic matter undergo assimilation and oxidation. As the suspended solids (SS) undergo oxidation, a portion of these are deposited also.

The settled sludge undergoes anaerobic decompostion. The degree of decomposition is directly related to temperature. The byproducts of anaerobic decomposition are diffused into the aerobic liquid to undergo further oxidation. In the presence of sunlight, algal growth also occurs, converting carbon dioxide into organic compounds and oxygen.

Four principal biological transformations which occur in all types of lagoons are described by Oswald (1968). These are: (1) aerobic oxidation which produces bacterial sludge, carbon dioxide and water; (2) anaerobic decomposition which produces organic acids and related compounds; (3) organic acid decomposition which forms methane and carbon dioxide; (4) algal growth which converts carbon dioxide into organic compounds and free oxygen. Knowledge of these reactions is essential for an understanding of the facultative aerated lagoon.

BOD REMOVAL

Eckenfelder (1970) has presented the relationship which is used for lagoons approaching a completely mixed regime. Based on a material balance, the following first order reaction equation can be developed:

$$S_e/S_o = 1/(1+Kt)$$

where $K = k\,X_e$

S_o = Influent BOD

S_e = Soluble effluent BOD

X_e = Basin volatile suspended solids

t = Detention time, days

K & k = Removal rate coefficient.

Because of the present inability to define the rate of solids settling, etc., in an incomplete mix lagoon, the overall reaction rate coefficient K is generally used.

TEMPERATURE EFFECTS

The effect of temperature on biological process reaction rates can be predicted by the following relationship:

$$K_T \doteq K_{20}\theta^{(T-20)}$$

K_T = Desired reaction rate at temperature T

K_{20} = Known reaction rate 20°C

T = Temperature

θ = Temperature coefficient

Values of θ vary widely depending on the type of process considered.

Eckenfelder and England (1970) summarized temperature effects as follows:

Process	Range of θ	Temperature Range °C
Stabilization Pond	1.072 - 1.085	3-35
Activated Sludge	1.0 - 1.041	4-45
Aerated Lagoon	1.026 - 1.058	2-30
Trickling Filter	1.035	10-35
Aerobic Facultative Lagoon	1.06 - 1.18	4-30
Anaerobic Lagoon	1.08 - 1.10	5-30
Extended Aeration	1.037	10-30

MIXING AND SHORT-CIRCUITING

Flow through lagoons have been described as either plug or complete mix as characterized by the following equations:

Plug Flow $S_e/S_o = e^{-kt}$

Complete Mix $S_e/S_o = 1/(1+Kt)$

Thirumurthi (1969), indicated that neither condition exists in sanitary engineering practice and that actual conditions are somewhere in between. He presented an equation for organic removal which included a dispersion coefficient which would account for short-circuiting and mixing characteristics, exit and entrance conditions, etc. Murphy and Wilson (1974) have also reported that lagoon mixing patterns differ significantly from either complete mixing or plug flow conditions and used a dispersion coefficient in describing organic removals. These methods require extensive knowledge of lagoon characteristics. Murphy and Wilson suggested that the following equation be used for rapid analysis of aeration basins in series.

$$S_e/S_o = \prod_{i=1}^{n}(1/(1+Kt_i))$$

t_i = Residence time for each respective cell.

The provision of a number of aeration cells in series will improve lagoon performance by reducing the opportunity for short-circuiting and by providing conditions more closely related to plug flow. Gloyna and Aguirre (1970) reported greater suspended solids and bacterial reductions in facultative ponds operated in series compared to single cell units. Reid (1975) has suggested that providing more than four cells in series will not improve performance significantly.

Some mixing is required to provide adequate dissolved oxygen levels throughout the lagoon. In general, this is accomplished when sufficient aeration is supplied for biological oxidation. Mixing also prevents thermal stratification and allows the bottom sludge to warm up during the summer months which should increase anaerobic activity.

SLUDGE ACCUMULATION

Because of the low mixing levels which occur in long detention time lagoons, deposition of biological sludge occurs. Clark et al. (1970), summarized cold climate facultative pond installations and reported accumulations of 250-400 liters per 1000 people per day (8.8 - 14.0 cu. ft./1000 people-day).

Middlebrooks et al. (1965), in an investigation of sludge accumulation in lagoons, determined that where the percentage of total solids is high the volatile portion is generally low. This condition would indicate that a large portion of the sludge must be silt and other inorganic matter washed into the lagoon. The time required for thorough digestion in sludge lagoons is estimated at 3 years (Vesilind, 1975). For streams in temperate climates, Fair has estimated the rate at which sludge deposits stabilize as follows (Mueller and Su, 1972):

50%	0.3 years
90%	1.5 years
99%	5.4 years

These values indicate that it takes at least 5 years for an aerated lagoon to reach equilibrium and to complete the aging process.

ALGAE

Algae exist in lagoons in a symbiotic relationship with bacteria and require H_2O, inorganic nutrients and carbon dioxide for growth. Typical green algae found in lagoons are Chlorella, Chlamydomonas and Euglena with the latter two tending to dominate in cooler weather (Gloyna, 1968).

Studies have shown that massive algal blooms are associated with excessive amounts of decomposable organic matter and that CO_2 is the major nutrient required for growth (Kuentzal, 1969), (Foree and Wade, 1972). Kuentzal (1969) reported that bacterial action on large amounts of organic matter can supply as much as 20 mg/l of CO_2 in a super saturated state and result in large algal bloom development.

Waste stabilization ponds which receive optimum amounts of waste for growth conditions discharge planktonic algae whereas, in ponds receiving relatively small loads, the algae settle out and/or are consumed by planktonic phagotrophs such as Daphnia or Cyclops (Gloyna, 1968). Dinges (1975) has described the environment desirable for cultivating zooplankton, which he indicated can filter and consume bacteria, colloids and algae in stabilization ponds. He suggested the following:

(1) pH should be maintained between 7.0 and 8.0. Ammonia dissociates at high pH levels and becomes toxic to a variety of zooplankton. High pH results from excessive algae growth. Algae can be controlled by reducing organic carbon which is converted to carbon dioxide by bacterial respiration.

(2) Dissolved oxygen should be 1 mg/l or greater as the zooplankton will not survive under anaerobic conditions.

(3) Gentle mixing should be present to prevent pockets of stagnation and preclude soluble sulphide evolution. Wind action can generally provide sufficient mixing.

(4) Rubble will increase the productive potential by providing living space.

COLIFORMS

A reduction in coliforms of several orders of magnitude occurs in aerated lagoon and oxidation pond treatment systems. Disinfection may be necessary, however, in order to meet state water quality standards. The disinfection step in aerated lagoon design apparently receives little attention other than to provide a contact chamber of a certain nominal retention time and a means of feeding chlorine to the effluent stream.

Two aspects of disinfection of aerated lagoons in the sub-arctic must be considered: the algae blooms which occur during the warm summer months of long daylight hours, and the long period of near 0°C effluent temperatures during winter months, which increases pathogen survival rates and affects disinfection requirements. Both situations require special attention in the design of lagoon treatment systems.

Slanetz et al. (1970) found die off rates of 95-99% in wastewater oxidation systems utilizing one pond or two ponds in series at 17-26°C. The ponds were 5 to 10 acres in size. Much better survival rates were found in the winter at pond temperatures of 1-10°C. Salmonellae and viruses were isolated in the majority of effluent samples. Systems having 3 or 4 ponds in series resulted in very few indicator bacteria remaining in the effluent. The numbers of bacteria were again much higher in the winter and enteric pathogen isolations more frequent. Gordon

(1972) has shown the survival rates of indicator bacteria are much greater in subarctic streams under winter conditions.

Mixing is very important for efficient chlorine disinfection. White (1972) has shown that high suspended solids levels have little effect on chlorine requirements when adequate premixing is provided.

The chlorination of treated wastewater effluents at 0-10°C have been investigated in a model contact chamber at the AERS (Gordon et al. 1973). The results of the study indicated that effective chlorination can be accomplished at temperatures less than 1°C provided an actual contact time of no less than one hour is provided and adequate premixing of the chlorine is practiced. These conditions seldom occur in practice. The authors reported a nominal detention time of 2 hours was necessary in the well baffled contact chamber model to provide a one-hour actual contact time.

A number of studies indicate that successful chlorination of algae laden oxidation pond effluents can be attained; however, the BOD of treated wastewater effluent containing algae can be increased by excessive chlorination (White, 1972). Hom (1970) suggested that two reactions appear to occur: first, the algae suffer surface damage and, second, the cellular contents are released which increases the BOD. Bacteria can be destroyed and the algae left essentially intact by controlling time of reaction and concentration of chlorine. The following optimal conditions were reported:

	Chlorine (mg/l)	
Contact Time (Min)	Applied	Residual
15	5.0	2.4
60	3.4	1.0

Kott reported work on 5 simulated pond effluents using raw and secondary treated domestic sewage in which no algae kill occurred with up to 2 hours detention time and 8-14 mg/l chlorine dosages (White, 1972). Indicator bacteria were reduced from 10^5 and 10^7/100 ml down to less than 20/100ml after 30 min. at 30°C. White (1972) recommended the chlorination chamber for wastewater ponds be designed for one hour contact time at average flow but not longer than two hours. The velocity should be 2 ft/min. to prevent deposition of dead algae and adequate provisions for cleaning should be made. The chlorination equipment should provide for 15 mg/l dosage at maximum flow.

AERATION

Oxygen requirements based on biological sludge synthesis and respiration and the bottom sludge demand have been discussed by Pohl (1970). The relationship for the synthesis of new cellular material is expressed as follows (Eckenfelder and O'Connor, 1961):

$$S = aL_r - bS_a$$

where S = net accumulation of Volatile suspended solids

a = fraction of 5 day BOD removed which is synthesized to new biological sludge

L_r = lb/day BOD removed

b = rate of endogenous respiration, fraction per day

S_a = lb of mixed liquor volatile suspended solids.

The oxygen required per day for synthesis and respiration is determined by the following equation (Eckenfelder, 1970)

$$\text{lb } O_2/\text{day} = a'\ S_r + b'\ \text{MLVSS}$$

a' = 1-a based on ultimate BOD

b' = 1.4b

For the 5 day BOD, the following conversion must be used

$$a' = BOD_u/BOD_5 - 1.42a$$

In aerated lagoons in which solids deposition is allowed to occur and BOD is fed back to the liquid from anaerobic fermentation, the following relationship can be used:

$$\text{lb of } O_2/\text{day} = a''\ \text{lb } BOD_5 \text{ removed/day}$$

Values of a'' should be 1.2 to 1.4. In other words, the oxygen requirement for oxidation of digestion products is increased by 20 to 40%. Endogenous respiration is ignored because of the low suspended solids level in the basin.

The aeration system requirements for aerated lagoons have been reviewed elsewhere (Christianson and Smith, 1973). Surface aerators are not recommended for cold climate operations because of icing problems which occur (Penman, 1970), (Clark et al., 1970).

OXYGEN TRANSFER

The general transfer equation for oxygen in wastewater is as follows:

$$dc/dt = \alpha K_L a(\beta C_s - C) - r$$

dc/dt = Change in concentration (mg/l-hr)

$K_L a$ = Overall transfer coefficient (hr^{-1})

α = Ratio of $K_L a$ in a wastewater to $K_L a$ of tapwater

C_s = Oxygen saturation concentration (mg/l)

C = Oxygen concentration in liquid (mg/l)

β = Ratio of C_s in wastewater to C_s in tapwater

r = Oxygen Demand Rate (mg/l-hr)

The overall oxygen transfer coefficient K_La, can be used for determining the performance of aerators. Examination of the above equation shows that when a biological system is operating under steady state conditions, the rate of oxygen transfer will equal the oxygen demand rate. Therefore, by determination of the oxygen demand rate, α , β , and oxygen in the liquid, K_La can be calculated (Benjes, 1969), (Conway and Tumke, 1966), (Eckenfelder, 1959).

Several attempts have been made to predict the value of K_La in diffused air systems. Eckenfelder, 1959 has shown that for a given aerator, K_La is influenced by air flow rate, depth of diffuser submergence and the tank and aerator configuration. Smith (1970) has shown that diffused air systems can be scaled up geometrically. The following equation was developed by Eckenfelder:

$$K_La = \frac{C\ G_s^{(1-n)} H^{2/3}}{V}$$

C = Constant

G_s = Air flow rate per diffuser

H = Liquid depth

V = Basin volume per diffuser

(1-n) = Gas rate exponent characteristic of diffuser type

The exponent of 2/3 for H has been found to vary for commercial aeration tanks with the values of 0.88 for sparjers and 0.72 for saran tubes reported (Eckenfelder and Ford, 1968).

Eckenfelder 1961 has indicated surface transfer in lagoons will be 10 - 20 percent of the total. Since the transfer rate is independent of diffuser spacing provided the spacing is sufficient to minimize interfering bubble patterns (Eckenfelder, 1968), diffuser placement is not expected to be a factor in larger aeration basins.

The difference between the oxygen saturation concentration and the concentration in the liquid is the driving force for the transfer process. The average saturation value (C_s) at tank mid-depth is used and may be determined as follows (Eckenfelder and O'Connor, 1961).

$$C_s = C_w(P_b/29 + O_t/42)$$

where C_w = Oxygen saturation concentration at barometric pressure

P_b = Psia at aerator depth

O_t = Percent oxygen by volume in air leaving tank

Regarding the effects of wastewater on C_s, the effect is relatively minor when the dissolved solids in an aeration basin are less than 0.2 percent. Values of 0.95 have been found for β where dissolved solids were in this range (Pfeffer, 1969).

The effect of wastewater on K_La is considerable more difficult to evaluate and extreme care must be used in its application. Eckenfelder and O'Conner (1961) and Eckenfelder and Ford (1968) list α values for various wastes and aerators. They indicate, however, that evaluation of α requires measurement of the respective K_La values under mixing intensities and surfactant levels found in practice.

The K_La value is also influenced by temperature which may be accounted for through the Arrhenius temperature correction equation related to 20°C as follows:

$$K_La(T) = K_La(20)\theta^{(T-20)}$$

θ = Temperature Coefficient

T = Temperature, °C

Pfeffer (1969) stated that reported values of θ range from 1.016 to 1.047 and that 1.024 is frequently used. He suggested that in most practical systems the value will be between 1.02 and 1.03. Eckenfelder and Ford (1968) indicated an evaluation showed θ to be 1.02 for K_La in a bubble aeration system. Hunter and Ward (1972) found that K_La varies linearly with temperature. However, their data show a relatively small difference between the use of 1.024 for θ in the Arrhenius equation and the linear model between 0°C and 25°C.

The following is a brief description of some submerged aeration devices which have been utilized in aerated lagoons:

1. Perforated tubing diffusers (Air Aqua Systems) supplied by Hinde Engineering Company, Highland Park, Illinois, consists of flexible plastic tubing with perforations cut on the top and a lead keel on the bottom to keep it submerged. This type of aeration was originally used for the upgrading of stabilization lagoons.

2. Porous ceramic diffusers supplied by Hydro Ceramic Company, Anchorage, Alaska (Pohl, 1970). Consists of PVC tubing with porous ceramic stones inserted one foot apart. Each stone provides about 3.2 sq cm of surface area. The tubing is supported off the lagoon bottom by pylons.

3. Air Gun aerators supplied by Aero-Hydraulics Corp., Montreal (Dutton and Fisher, 1966), (Penman, et al., 1970). These consist of submerged vertical plastic pipe normally 30 cm in diameter and of varying lengths with an air chamber at the lower end. Air is pumped into the chamber and builds up until released by a siphoning effect through the pipe. The rising air bubble "piston" draws in water from holes in the pipe located just above the air chamber and a pumping action occurs. Air Gun aerators are designed for use in deeper lagoons and promote mixing as well as oxygenation.

4. The INKA aeration system designed by Industrikemeska Aktiebologet of Stockholm, Sweden, was studied in a pilot lagoon at Laramie, Wyoming (Champlin, 1971). The INKA aeration system is designed for low pressure operation and in this case consisted of three grids of 1 m X 2.5 m with 5 mm orifices located on the bottom of the grid. The grids were placed at a depth of 0.8 m below the surface and circulation in the lagoon was controlled by baffling.

5. Aer-O-Flo non-clog diffusers supplied by Aer-O-Flo Corporation, Florence, Kentucky. Consists of a cap which rests on a 3 mm pipe orifice. When air is flowing, differential pressure raises the cap about 1.6 mm. Air flows radially under the cap, theoretically rising through small holes in the cap. When air is shut off, the cap falls back against the orifice and prevents solids from backing up in the system, simulating a check valve.

6. Chicago Pump Shearfusers supplied by Chicago Pump Co., FMC Corp., Chicago, Illinois. Consists of a box 19 cm square with a one-inch air injection orifice entering the side near the bottom. As air rises in the box, water is pulled in and the resulting shearing action causes the air to break up into smaller bubbles.

7. Kenics Aerator supplied by Kenics Corporation, Danvers, Massachusetts. The aerator is a motionless mixer consisting of a polyethylene tube and alternating right and left hand helices. The units act as air lift devices.

LAGOON DESIGN

That lagoons can be designed and operated to meet the standards has been demonstrated. Oswald et al. (1970) described a lagoon system at Saint Helena, California, which achieved excellent effluent characteristics including an average BOD level of 3.9 mg/l. The lagoon system consisted of facultative, aeration, algae sedimentation and two maturation ponds, all in series and totaling 110 days detention time. Other methods of meeting standards without the need for polishing filters, etc., have also been described. Pierce (1974) reported on 49 lagoons in Michigan practicing long term storage prior to effluent release. He indicated that lagoons can produce effluents meeting EPA requirements for BOD and fecal coliforms and generally can meet the suspended solids requirements by practicing long term storage and discharging in the spring and fall. Hiatt (1975) reported on a pilot program of phase isolation in which lagoon effluents were transferred to a pond and held for 2 weeks before discharge. Excellent results were obtained with extreme reductions in the algae populations, apparently due to the change in conditions experienced by the algae after transfer to the holding pond.

Oswald et al. (1970) has suggested that optimum removals cannot be obtained from any one type of lagoon because of the many different biological processes which occur. Optimum conditions for one process will not necessarily be optimum for another. He has suggested that different types of lagoons operating in series are necessary for an optimum lagoon system.

METHODS OF ANALYSIS AND LAGOON DESCRIPTION & PERFORMANCE CHARACTERISTICS

GENERAL INFORMATION

Following is a brief summary of some subarctic aerated lagoon performance information which supports the conclusions presented in this report. Information included in this section has been obtained from experimental and full scale aerated lagoons located at Eielson Air Force Base (EAFB), Northway, Ft. Greely, Eagle River and Palmer. The EAFB experimental lagoon was part of an experimental facility constructed jointly by the Alaskan Air Command and the Arctic Environmental Research Station.

The EAFB, Northway and Ft. Greely lagoons are discussed primarily in reference to effectiveness of multiple cells, short-circuiting, sludge accumulation, and algae production. The Eagle River and Palmer lagoons were included to allow comparison of two full scale lagoons of different design, operating under similar conditions.

The climate at EAFB, Northway, and Ft. Greely is very similar to that of Fairbanks, which is located at 64 1/2 °N latitude. The mean annual temperature at Fairbanks is approximately -4°C. The sunshine varies from a winter low of approximately 3 3/4 hours to a summer maximum greater than 22 hours. The Palmer and Eagle River lagoons are located near Anchorage where the mean annual temperature is about 2°C and the hours of sunshine vary from 5 1/2 hours in the winter to 19 1/4 as a summer maximum.

Biochemical oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids (SS) data (if available) are summarized for each of the lagoons discussed. Winter and summer operation refers to periods when the lagoon effluent temperature was less than 1°C and greater than 10°C respectively.

"Fine bubble diffusers", as used hereafter, refer to restricted diffusers such as the perforated tubing and porous ceramic types. "Coarse bubble diffusers" refer to larger orifice types such as the Aer-O-Flo or Shearfuser diffusers.

SAMPLING AND ANALYSIS

All analyses for the Eielson experimental Ft. Greely and Northway lagoons were performed at the Arctic Environmental Research Laboratory in accordance with Standard Methods, (1965, 1971). Samples for the Eagle River and Eielson full scale lagoon were collected by the Greater Anchorage Borough Public Works Department and Eielson AFB personnel respectively and analyzed in accordance with standard methods. The Palmer lagoon samples were collected by city employees and analyzed with Hach field equipment.

Eielson Air Force Base Experimental Lagoon

Eielson plant lagoon feed samples were 24-hour composites collected with a surveyor sampler supplied by N-Con Systems Company, Inc. Cell samples were grab and were collected by means of a pump through insulated and heat-taped tubing which entered each cell at mid-depth and extended approximately 1 foot into the liquid. Samples were generally collected once per week and analyzed for pH, BOD (5-day, 20°C), COD, solids and coliform indicators. Nutrient samples were collected once per month. Each sample line was flushed before collection. The samples were immediately placed in an ice chest and returned to the laboratory within 2 to 3 hours for analysis the same day. COD and nutrient samples were occasionally preserved by freezing for later analysis.

Problems were encountered during the last few months with plugging of the cell 5 sampling tube. As a result, some samples were missed and those that were collected appeared to give low results. These were not included in the data analyses.

Fort Greely Lagoon

Nearly all of the Ft. Greely influent samples were collected using a composite sampler. An N-Con Systems Company trebler oscillating scoop proportional sampler was originally utilized in the Palmer Bowlus flume before the lift station but was abandoned because of fouling by large solids particles. A home-made sampler was then constructed which consisted of a container with an inlet tube which was placed in the splitter manhole. Each time the lift pumps operated, liquid would rise above the inlet tube and run in the collection container during the short period the pumps were in operation. This proved to be an improvement because the solids were largely pulverized by the lift pumps before reaching the splitter manhole.

All effluent samples were grab. Each sampling operation required at least two days. The general procedure was to drive to Ft. Greely in the evening two days before sampling or in the early morning one day before, in order to set up the influent sampler to obtain a 24-hour composite. Sampling was then accomplished in the early morning on sampling day, packed in an ice chest, and driven back to the laboratory for analysis the same day, usually within 3 to 5 hours. Analysis included BOD, COD, solids and nutrients. pH was performed in the field with a Porto-matic, Model 175 meter supplied by Instrument Laboratories. Dissolved oxygen (D.O.) levels were obtained in the field with a Model 54 meter supplied by Yellow Springs Instrument Company. The D.O. instrument was calibrated before leaving the laboratory in saturated water at the expected lagoon temperature and the calibration checked on return from the sampling trip. During the cold weather, the instrument was kept in a specially fabricated, insulated box while obtaining the lagoon D.O. levels.

Northway Lagoon

Northway lagoon effluent samples were also grab while the influent samples were composite. The composite samples were obtained from a tap in the discharge line from the lift pump. Each time the lift pump operated, a small amount of sample was forced through tubing into a collection container. Generally, the same procedure was followed for Northway lagoon sampling as for Ft. Greely. Samples were collected in the early morning, packed in an ice chest and transported back to the laboratory for analysis the same day. Because of the longer distances involved, a lag of 6 to 9 hours normally occurred between collection and analysis. Analyses were essentially the same as for Ft. Greely.

EIELSON AIR FORCE BASE EXPERIMENTAL AERATED LAGOON

Lagoon Description

The EAFB experimental lagoon (Figure 1) consisted of six cells operated in series. During the latter part of the study the lagoon was converted to four cells operating in series. It was fed raw domestic sewage. The lagoon consisted of a wood crib structure with vertical sides and lined with a 20 mil polyvinyl chloride (PVC) membrane. Dimensions were 4.6m X 25.2m X 3.7m deep for an operating volume of 420 m^3. Detention time per cell was as follows:

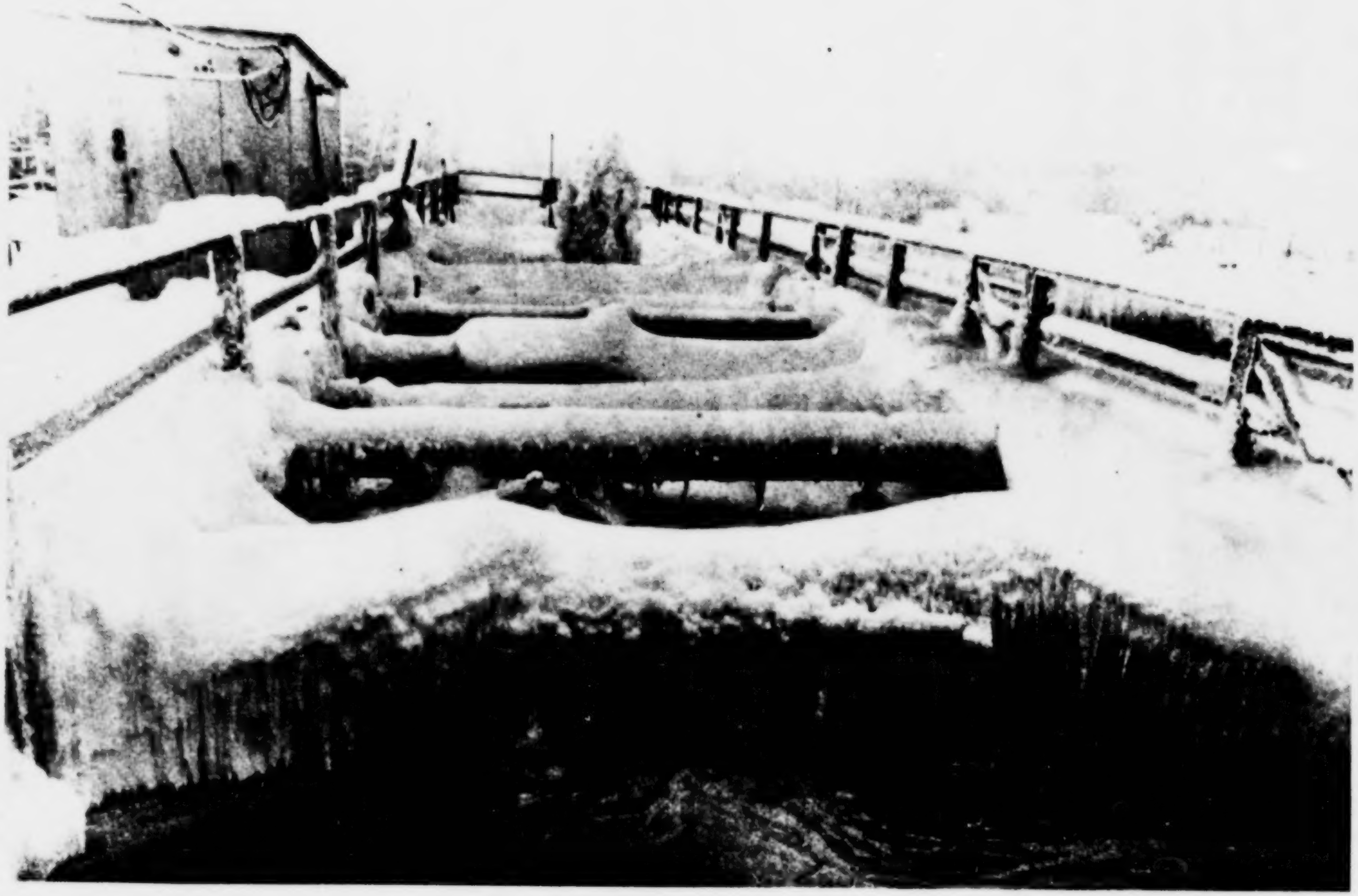

Figure 1. Eielson Air Force Base Experimental Lagoon.

Cell No.	- 1	2	3	4	5	6	Total
Detention Time (days)	- 1.8	2.9	3.6	5.4	7.3	9	30

Flow measurement and control was accomplished with a dump tank and a timer on the feed pump and a "V" notch weir in the lagoon effluent structure. In the lagoon, each cell was fed from the previous cell through a 51mm diameter X 3m long suction hose coiled and hung above the aerators. The feed temperature was a fairly constant 20°C because of heated utilidors.

Initial startup of the lagoon began in September, 1968 with aeration provided by fine bubble diffusers. These consisted of 16 mm (5/8 in.) OD flexible plastic tubing with 8 slits per foot on top and a lead keel on the bottom to keep it submerged (Hinde Engineering Company, Highland Park, Illinois). The tubes were placed perpendicular to the line of flow and supported 40 cm above the bottom to prevent sludge plugging.

Because of clogging problems and resulting high compressor discharge pressures encountered with the perforated tubing, the lagoon was modified in January 1970 by replacing the tubing with coarse bubble diffusers manufactured by Aer-O-Flow Corporation, Florence, Kentucky. The lagoon was then operated through May 1972 (over two years) with no change in compressor discharge pressure and no maintenance problems due to the aeration system.

The Aer-O-Flow diffuser consisted of a cap which rested on a 1/8 inch pipe orifice. When air was flowing, the cap was forced up about 1.5 mm and air flowed under the cap and, theoretically, up through the small holes in the cap. When air was shut off, the cap would fall back against the orifice and prevent solids from backing up in the system.

Operation Problems

Clogging of the perforated tubing proved to be a problem during the first year in the first two cells where the solids concentration was greatest. Cleaning was accomplished by applying hydrochloric acid at a rate of 50 g/m on one occasion and applying hydrogen chloride gas at a rate of 9 g/m on three occasions. Each time the compressor discharge pressure would drop to 0.50 to 0.56 kg/cm^2 after cleaning and climb back to 0.63 to 0.70 kg/cm^2 within a few days. Both cleaning methods were ineffective in the first two cells and replacement of tubing was found necessary twice.

In the case of gas cleaning, adequate valving was not provided, and the gas passed through the less restricted tubing in the last 4 cells restoring the aeration patterns in those cells but not in the first two cells. Dissolved oxygen levels were generally less than 1/2 mg/l in the first two cells during this period.

Problems were also encountered with leaking of the PVC liner during the first summer's operation. Bentonite was added to the first two cells in July and August and the lagoon pumped down in September 1969 when the leakage continued. Repairs to the lining were made and the lagoon placed back in operation in October 1969. Some leakage still occurred which a further addition of bentonite had stopped by late November 1969.

Minor leakage continued to be a problem and the lagoon was pumped down during the summer of 1970 for more repairs to the PVC lining. Leakage problems somewhat more severe were encountered during the winter of 1970 - 1971; however, no attempts have been made to adjust the data.

After installation of the Aer-O-Flo non-clog diffusers in January, 1970, the compressor discharge pressure and temperature immediately dropped from greater than 0.63 kg/cm^2 and 90°C to 0.42 kg/m^2 and 32°C, and the dissolved oxygen (DO) in the first two cells rose to more than 5 mg/l. The lagoon was then operated through May 1972 (over two years) using the Aer-O-Flo diffusers with no change in compressor discharge pressure and no maintenance problems due to the aeration system.

BOD and SS Removals

A summary of BOD and SS removals for the EAFB experimental lagoon is presented in Table 1. Removal data for both the perforated

Table 1. Performance Summary of Eielson Air Force Base Experimental Lagoon

Period	Station	Detention Time (Days)		Loading (g BOD_5/m^3-day)		BOD_5				
		Per Cell	Accum.	Per Cell	Accum.	Mean	Stand Dev.*	Number Samples	Percent Removal Per Cell	Percent Removal Accum
Six Cell Operation First 18 Months	Inf	-	-	-	-	319	109	40	-	-
	Cell -1	1.8	1.8	177.2	177.2	151	71	55	53	53
	-2	2.9	4.7	51.5	67.8	108	47	58	28	66
	-3	3.6	8.3	30.0	38.4	60	34	56	44	81
	-4	5.4	13.7	11.1	23.2	40	25	56	33	87
	-5	7.3	21.0	5.5	15.2	26	11	51	35	92
	-6	9.0	30.0	2.9	10.6	26†	10	58	3	92
First Year Winter Fine Bubble Aeration	Inf	-	-	-	-	303†	154-553	9	-	-
	Cell -1	1.8	1.8	168.3	168.3	137	45	17	55	55
	-2	2.9	4.7	47.2	64.3	118	38	20	14	61
	-3	3.6	8.3	32.8	36.5	54	26	18	54	82
	-4	5.4	13.7	10.0	22.1	34	15	17	37	89
	-5	7.3	21.0	4.7	14.4	27	12	17	22	91
	-6	9.0	30.0	3.0	10.1	28†	13	19	0	91
Second Year Winter Coarse Bubble Aeration	Inf.	-	-	-	-	362	105	21	-	-
	Cell -1	1.8	1.8	201.1	201.1	180	91	21	50	50
	-2	2.9	4.7	62.1	76.8	122	56	21	32	66
	-3	3.6	8.3	33.9	43.5	85	36	21	30	76
	-4	5.4	13.7	15.7	26.4	58	30	21	32	84
	-5	7.3	21.0	8.0	17.3	29	10	15	50	92
	-6	9.0	30.0	3.2	12.1	21	10	21	30	94

(Continued)

Table 1. Continued

		COD					SS				
					Percent Removal					Percent Removal	
Period	Station	Mean	Stand Dev.*	Number Samples	Per Cell	Accum.	Mean	Stand Dev.*	Number Samples	Per Cell	Accum
Six Cell Operation											
First 18 Months	Inf	509	175	31	-	-	261	128	42	-	-
	Cell -1	262	106	46	49	49	138	46	58	47	47
	-2	227	87	45	13	55	143	86	58	0	45
	-3	179	84	46	21	65	91	67	61	36	65
	-4	142	83	44	21	72	67	69	55	27	75
	-5	110	61	46	23	78	39	29	56	42	85
	-6	85†	38	45	23	83	23†	12	59	42	91
First Year Winter	Inf	315	176-464	6	-	-	218†	112	11	-	-
Fine Bubble Aeration	Cell -1	249	64	13	21	21	109	42	18	50	50
	-2	242	77	13	13	23	139	63	18	0	36
	-3	164	55	13	33	48	61	27	18	57	72
	-4	129†	57	12	21	59	38	18	17	37	82
	-5	121†	55	13	7	62	25	10	14	35	89
	-6	112†	41	13	7	65	18	10	17	29	92
Second Year Winter	Inf	568	103	15	-	-	278	131	21	-	-
Coarse Bubble Aeration	Cell -1	280	71	15	51	51	152	51	21	45	45
	-2	247	97	15	12	57	172	99	21	0	38
	-3	239	80	15	3	58	153	74	21	11	45
	-4	193	87	15	19	66	128	82	20	17	54
	-5	118†	44	15	39	79	45†	16	21	65	87
	-6	81	40	15	32	86	23	10	21	48	92

(Continued)

Table 1. Continued

Period	Station	Detention Time (Days)		Loading (g BOD_5/m^3-day)		BOD_5				
		Per Cell	Accum.	Per Cell	Accum.	Mean	Stand Dev.*	Number Samples	Percent Removal Per Cell	Percent Removal Accum
Six Cell Operation										
First and Second Year Winter	Inf	-	-	-	-	347	110	30	-	-
	Cell -1	1.8	1.8	192.8	192.8	161	76	38	54	54
	-2	2.9	4.7	55.5	73.8	117	50	41	27	66
	-3	3.6	8.3	32.5	41.8	71	35	39	39	79
	-4	5.0	13.3	14.2	26.1	47	27	38	33	86
	-5	6.4	19.7	7.3	17.6	28	11	32	27	92
	-6	7.5	27.2	3.7	12.8	24†	11	40	5	93
First and Second Year Summer	Inf	-	-	-	-	214	178-243	3	-	-
	Cell -1	1.8	1.8	118.9	118.9	133	77-205	5	38	38
	-2	2.9	4.7	45.9	45.4	85	52-409	4	36	60
	-3	3.6	8.3	23.6	25.8	34	29-173	4	61	84
	-4	5.4	13.7	6.3	15.5	33	19-49	5	0	84
	-5	7.3	21.0	4.5	10.2	30	7-45	5	11	86
	-6	9.0	30.0	3.3	7.2	29	8-45	5	2	86

(Continued)

Table 1. Continued

Period	Station	COD					SS				
		Mean	Stand Dev.*	Number Samples	Percent Removal Per Cell	Percent Removal Accum.	Mean	Stand Dev.*	Number Samples	Percent Removal Per Cell	Percent Removal Accum
Six Cell Operation											
First and Second Year Winter	Inf	496	156	21	-	-	264	136	32	-	-
	Cell -1	265	69	28	47	47	132	51	39	50	50
	-2	245	87	28	8	51	157	85	39	0	41
	-3	204	79	28	17	59	110	74	39	30	58
	-4	169	86	27	17	66	87	76	37	22	67
	-5	122	58	28	28	75	36(+)	16	35	58	86
	-6	99	55	28	19	80	21	10	38	42	92
First and Second Year Summer	Inf	360	334-404	3	-	-	192	95-338	4	-	-
	Cell -1	200	99-243	4	44	44	137	87-192	4	29	29
	-2	170	42-292	4	15	53	72	28-173	6	47	63
	-3	137	62-188	4	20	62	30	16-43	6	59	85
	-4	81	30-190	4	41	78	25	11-45	6	17	87
	-5	71	44-99	4	12	80	27	10-45	6	0	86
	-6	66	43-80	3	8	82	25	10-41	6	9	87

(Continued)

Table 1. Continued

Period	Station	Detention Time (Days)		Loading (g BOD_5/m^3-day)		BOD_5				
		Per Cell	Accum.	Per Cell	Accum.	Mean	Stand Dev.*	Number Samples	Percent Removal Per Cell	Percent Removal Accum
Four Cell Operation Third and Fourth Year	Inf	-	-	-	-	186†	61	61	-	-
	Cell -2	4.7	4.7	39.6	39.6	85	26	61	54	54
	-4	9.0	13.7	9.4	13.6	55	28	62	35	70
	-5 & -6‡	16.3	30.0	3.4	6.2	33	15	60	15	83
Third and Fourth Year Winter	Inf	-	-	-	-	190†	74	31	-	-
	Cell -2	4.7	4.7	40.4	40.4	94	21	31	51	51
	-4	8.6	13.3	10.9	14.2	59†	20	31	33	69
	-5 & -6‡	13.9	27.2	4.4	6.4	40	11	29	31	79
Third Year Summer	Inf	-	-	-	-	214	56	15	-	-
	Cell -2	4.7	4.7	45.5	45.5	71	17	15	67	67
	-4	9.0	13.7	7.9	15.6	47	22	15	34	78
	-5 & -6‡	16.3	30.0	2.9	7.1	19	10	15	60	91

(Continued)

Table 1. Continued

		COD					SS				
					Percent Removal					Percent Removal	
Period	Station	Mean	Stand Dev.*	Number Samples	Per Cell	Accum.	Mean	Stand Dev.*	Number Samples	Per Cell	Accum
Four Cell Operation											
Third and Fourth Year	Inf	320	98	62	-	-	145	88	56	-	-
	Cell -2	202	69	60	37	37	90	44	57	38	38
	-4	138	65	62	32	57	54†	33	57	40	63
	-5&-6‡	95	47	61	29	70	29	21	58	46	80
Third and Fourth Year											
Winter	Inf	320†	110	32	-	-	130†	70	28	-	-
	Cell -2	215	38	30	33	33	101	33	27	23	23
	-4	162†	52	31	25	49	69†	31	28	32	47
	-5&-6‡	125†	30	31	19	61	44	18	28	29	66
Third Year Summer	Inf	317	76	15	-	-	167	43	14	-	-
	Cell -2	165	44	15	48	48	73	49	15	56	56
	-4	94	44	15	43	70	60	90	15	18	64
	-5&-6‡	47	5	15	18	85	14	13	15	39	92

* The range is shown where the number of samples collected is less than ten.

† Adjusted from probability plot.

‡ Cell 5 Removals not shown due to sample collection problems during this period.

tubing and Aer-O-Flo diffuser systems operated under essentially the same conditions indicate little effect on process performance by the change in aeration devices, (Figure 2). An exception is the approximately 5 percent lower removals at around ten days detention time associated with the coarse bubble diffuser. This may have been due to a stirring up or shifting of the bottom sludge caused by the change in aeration devices. Overall BOD removal efficiencies for 4 cell and 6 cell operation are presented in Figure 3 along with the maximum ice buildup experienced during the winter of 1970. The winter data, referred to later, has been adjusted for average ice buildup using 1/2 of the maximum thickness reported for each cell.

The much lower removal efficiencies for the 4 cell operation has been attributed to a combination of aging due to sludge buildup and the provision of fewer cells in series. Both of these considerations are discussed later.

Winter and summer BOD removals and effluent SS levels are compared in Figure 4. Best removals were obtained during the first winter operation (6 cell) reaching greater than 90 percent at around 20 days dentention. Summer removals for the first year approach those for the winter at less than 15 days and then level off at around 86 percent. This can be ascribed to algae growth since algae were present in cells 2 through 6 during that summer. It should be noted that the first summer removals are based on

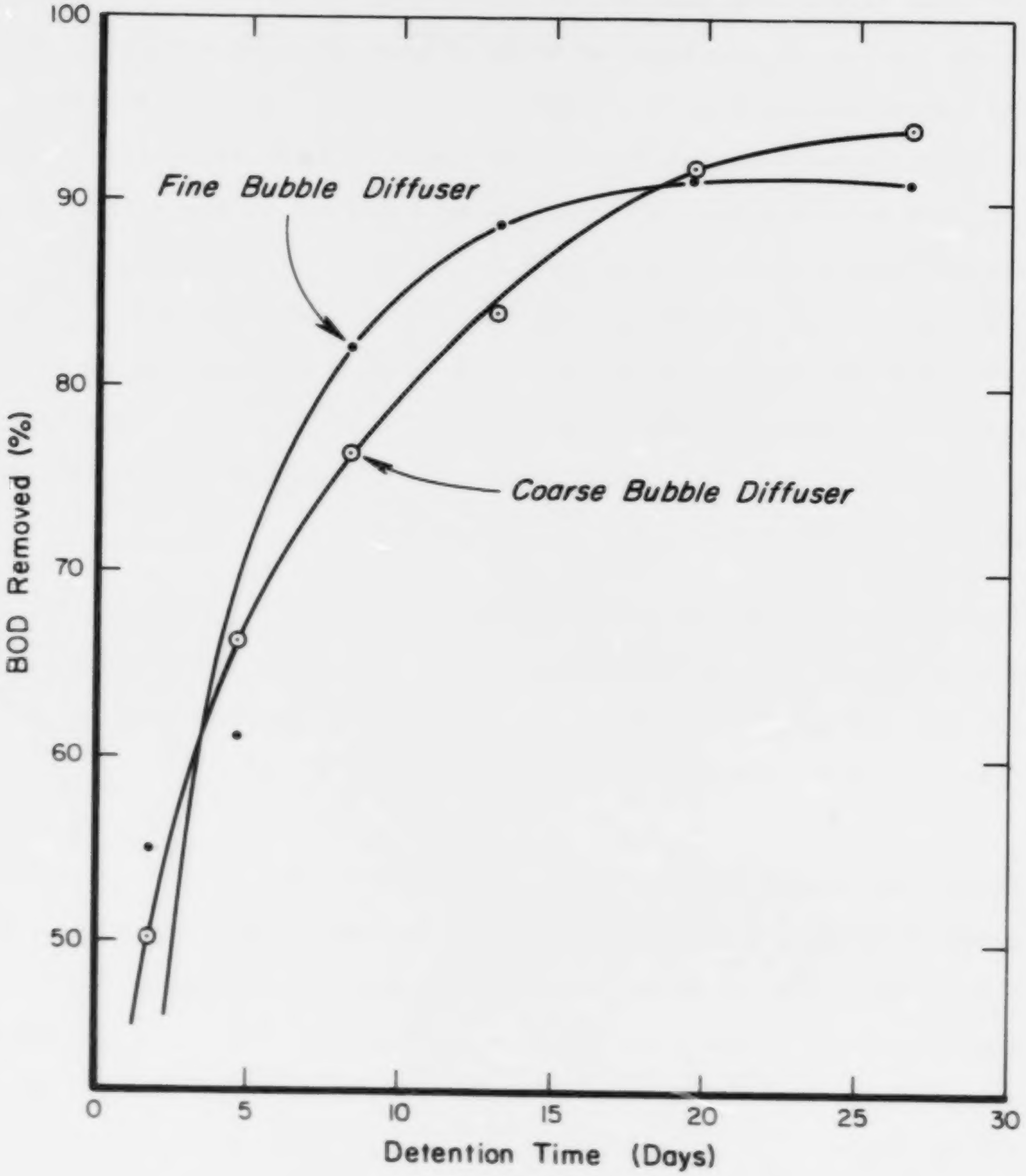

Figure 2. EAFB Experimental Lagoon performance with fine bubble and coarse bubble diffuser systems.

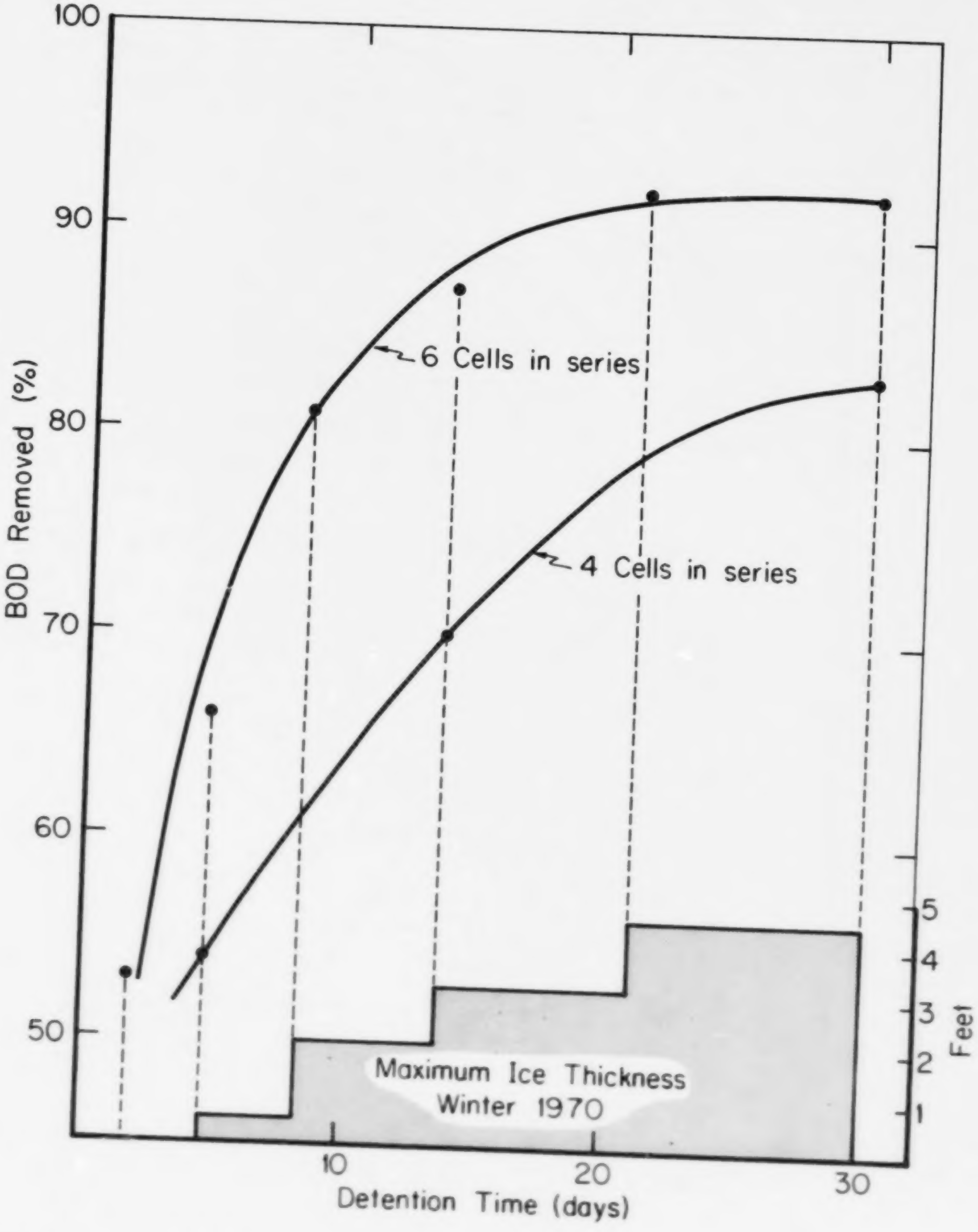

Figure 3. EAFB Experimental Lagoon performance with 6 cell and 4 cell operation.

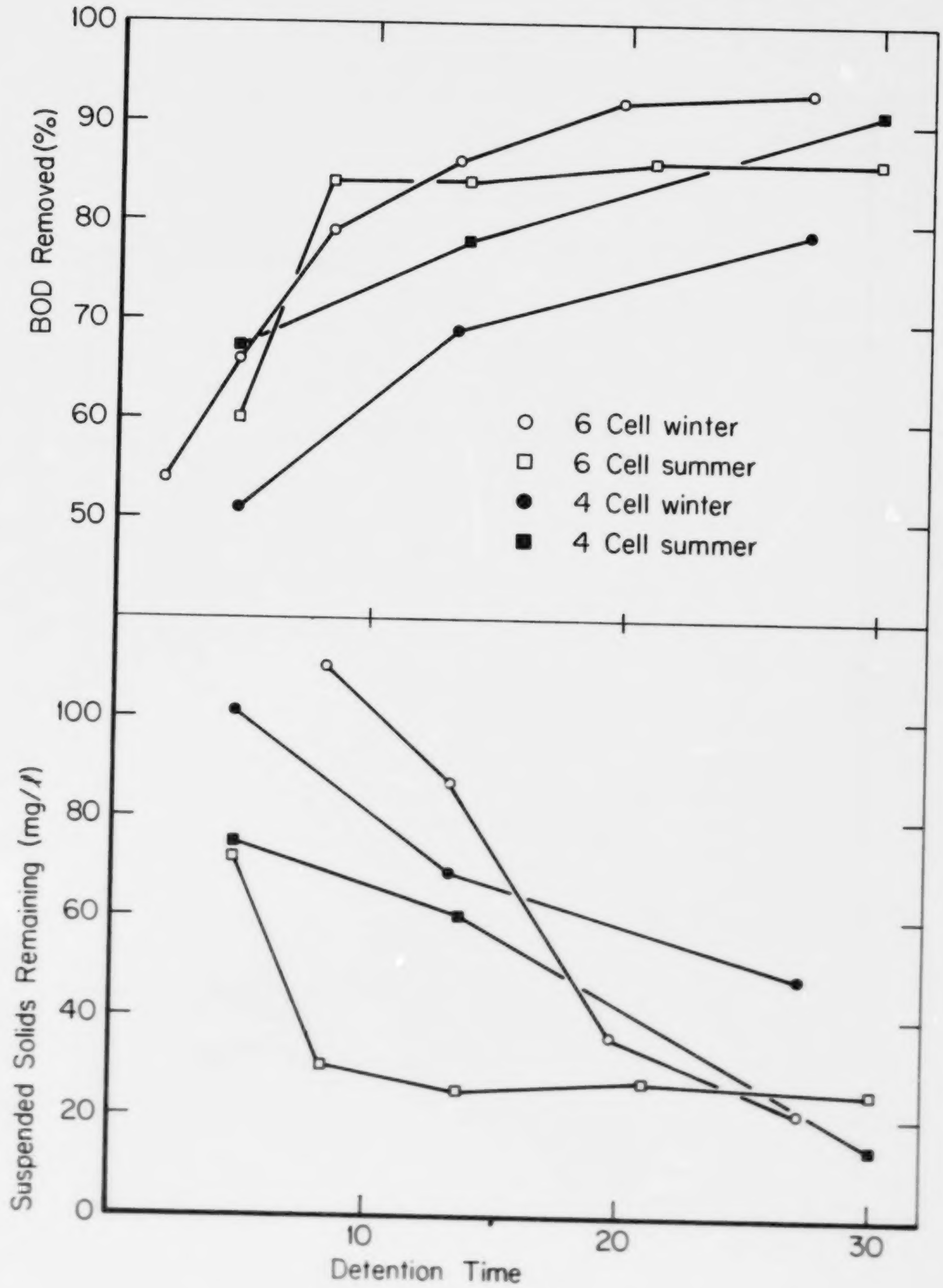

Figure 4. EAFB Experimental Lagoon winter and summer percent BOD removal and SS remaining vs. detention time.

5 data points only. The reduced BOD removal efficiency during summer is not considered the result of bottom sludge activity during the first year but may have been the result of a reduced degree of settling. Examination of the bottom sludge in cell 6, during the fall of 1969, indicated only a thin layer of flocculated algae.

The 4 cell summer data shows lower removals at approximately 15 days but increases to greater than 90 percent at 30 days. The lower removal at 15 days is attributed to aging of the lagoon while the greater removals at 30 days are attributed to a filtering action. The liquid in cells 5 and 6 of the EAFB lagoon was dark green with algae during June and part of July 1971. Chlorella appeared to be the predominant algae species. Green filamentous growth was also thick with stringers over 10 feet long attached to feeder air lines. During July a reduction in color was accompanied by the appearance of Daphnia. Effluent BOD's of less than 10 ppm were measured in late July and early August and were attributed to the Daphnia and the filtering action of the filamenmtous algae. Increased settling may also have contributed to the higher removals.

Algae Growth

Chlorophyll measurements were made on the lagoon in the early summer of 1969 (Figure 5). The highest chlorophyll reading in the 6th cell was 810m-SPU/m^3 (milli-Specific Plant Units/meter

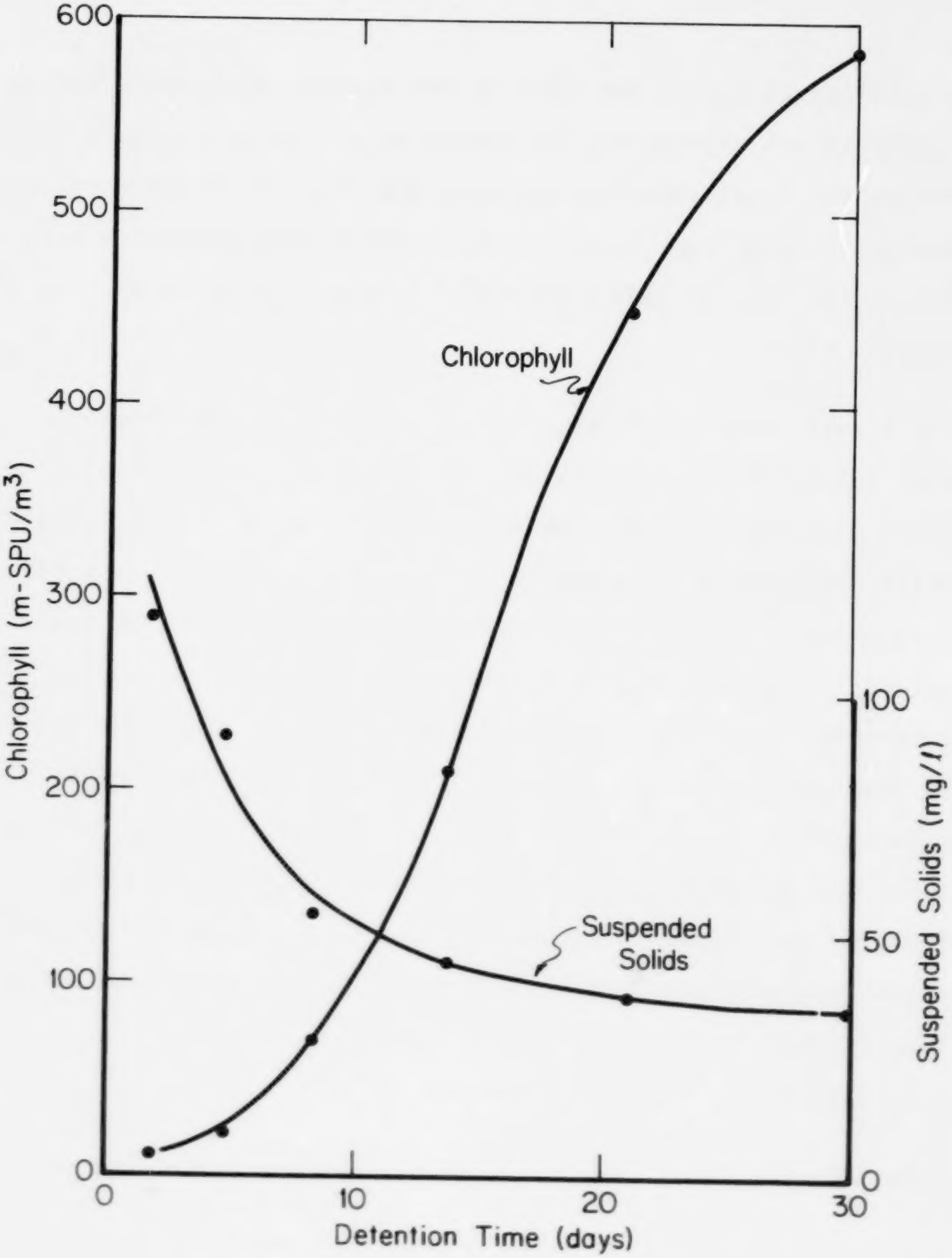

Figure 5. EAFB Experimental Lagoon chlorophyll and suspended solids vs. detention time.

cubed). The major algae growth began after approximately 10 days detention time and followed a typical growth curve. Information is available for only 30 days detention time and followed a typical growth curve, but presumably the curve would peak and begin to decline with time.

Coliforms

Fecal indicator organisms measured in the effluent of the EAFB 6 cell, 30 day lagoon during the summer of 1969 were (Clark et al., 1970):

	JULY	AUGUST
Total coliform	5500	1200
Fecal coliform	440	770
Fecal enterococci	126	64

Associated effluent temperatures were 15 - 16°C and the pH varied from 7.0 to 8.4.

Total coliform removals found in the EAFB experimental lagoon are presented in Table 2. As Expected, the dieoff of coliform bacteria is significantly more rapid in the summer. The 6 cells in series also resulted in higher dieoff rates than the 4 cells in series.

Table 2. EAFB Experimental Lagoon Total Coliform Removal Results*

Period	Influent	Cell Number 1	2	3	4	5	6
Six Cell Operation Winter 1/22/70-3/25/70	6.5×10^7	1.3×10^7	6.7×10^6	4.1×10^6	1.4×10^6	3.0×10^5	1.4×10^4
% Removal		80	90	94	98	99.5	99.98
Four Cell Operation Winter 1/29/71-3/24/71 & 1/5/72-3/29/72	7.3×10^7	1.2×10^7	1.8×10^6	-	1.1×10^6		
% Removal		84	98		98		
Four Cell Operation Summer 6/9/71-9/8/71	1.1×10^8	8.2×10^6	3.9×10^6	-	2.2×10^4		
% Removal		93	99.6		99.98		

* Values are geometric means

Nutrients

Nutrient removals for the EAFB experimental lagoon show little removal of NH_3-N or T-N during winter operations and significant removals in summer (Table 3). T-N removals in summer were less than NH_3-N, indicating a conversion of nitrogen to the organic form by algae. The phosphorus data indicate the net annual removals are zero. The phosphorus apparently had previously accumulated in the bottom sludge and was being released to the lagoon liquid by anaerobic action. Also the inherent inaccuracy of the organic phosphorus analysis may have contributed to the negative removal results.

FORT GREELY LAGOON

Lagoon Description

Because of the success with the Aer-O-Flo diffusers in the pilot facility, it was decided they should be demonstrated in a full scale lagoon. This led to an agreement with the U.S. Army, Alaska (USARAL), in the summer of 1971 which allowed AERS to modify part of the waste treatment lagoon at Ft. Greely.

The Ft. Greely lagoon was constructed in 1969 and had two cells which could be operated in series or in parallel. Each cell was separated into two smaller cells by a baffle which extended from the bottom to about 0.3 m below the water surface. The lagoon

Table 3. EAFB Experimental Lagoon Nutrient Removal Summary

Period	Station	Nutrient			
		HN$_3$-N (mg/l)	T-N (mg/l)	O-P (mg/l)	T-P (mg/l)
Six Cell Operation					
Winter	Inf	16	22	6	10
	Cell -1	15	21	8	13
	-2	15	21	8	14
	-3	17	26	9	15
	-4	17	26	9	14
	-5	17	22	9	15
	-6	17	21	10	16
% Removal		(-6)	5	(-67)	(-60)
Summer	Inf.	29	38	29	44
	Cell -1	25	32	36	49
	-2	28	33	36	50
	-3	27	32	39	48
	-4	26	28	37	47
	-5	20	30	37	46
	-6	15	33	38	41
% Removal		48	13	(-31)	7
Four Cell Operation					
Winter	Inf	14	19	7	9
	Cell -2	20	27	12	13
	-4	22	28	10	13
	-6	20	26	11	13
% Removal		(-43)	(-37)	(-57)	(-44)
Summer	Inf	24	30	8	10
	Cell -2	28	27	6	12
	-4	25	26	10	10
	-6	15	25	11	13
% Removal		38	13	(-38)	(-33)

was of earthen dike construction lined with PVC film and had 15cm of sand covering the bottom. The upper slope was covered with gravel. Each principal cell measured 61m x 61m at the base. The side slope ratio was 2 horizontal by 1 vertical. Volume was 29,000 m^3 at an operating depth of 3 m. The lagoon treated domestic sewage which has a fairly constant temperature of 20°C because of heated utilidors.

The aeration system of one half of the lagoon was modified in July 1971 (Figure 6). Two clusters of Chicago Pump Shearfusers (Chicago Pump, FMC Corporation, Chicago, Illinois) were installed in one cell (Figure 7). Shearfusers consist of a box about 18 cm square with a 2.5 cm air injection orifice entering the side. As the air rises in the box, water is pulled in through the hole in the other side and the resulting shearing action causes the air to break up into smaller bubbles. Aer-O-Flo diffuser clusters were installed in the second cell (Figure 8).

The two principal cells of the lagoon were operated in parallel for one year beginning in October of 1971.

Aerator Performance

Figure 9 gives information on the perforated tubing aerator performance. Some of the variability of the data is due to clogging problems encountered with the perforated tubing. That is, as the tubing began clogging, more air was diverted by the operator to

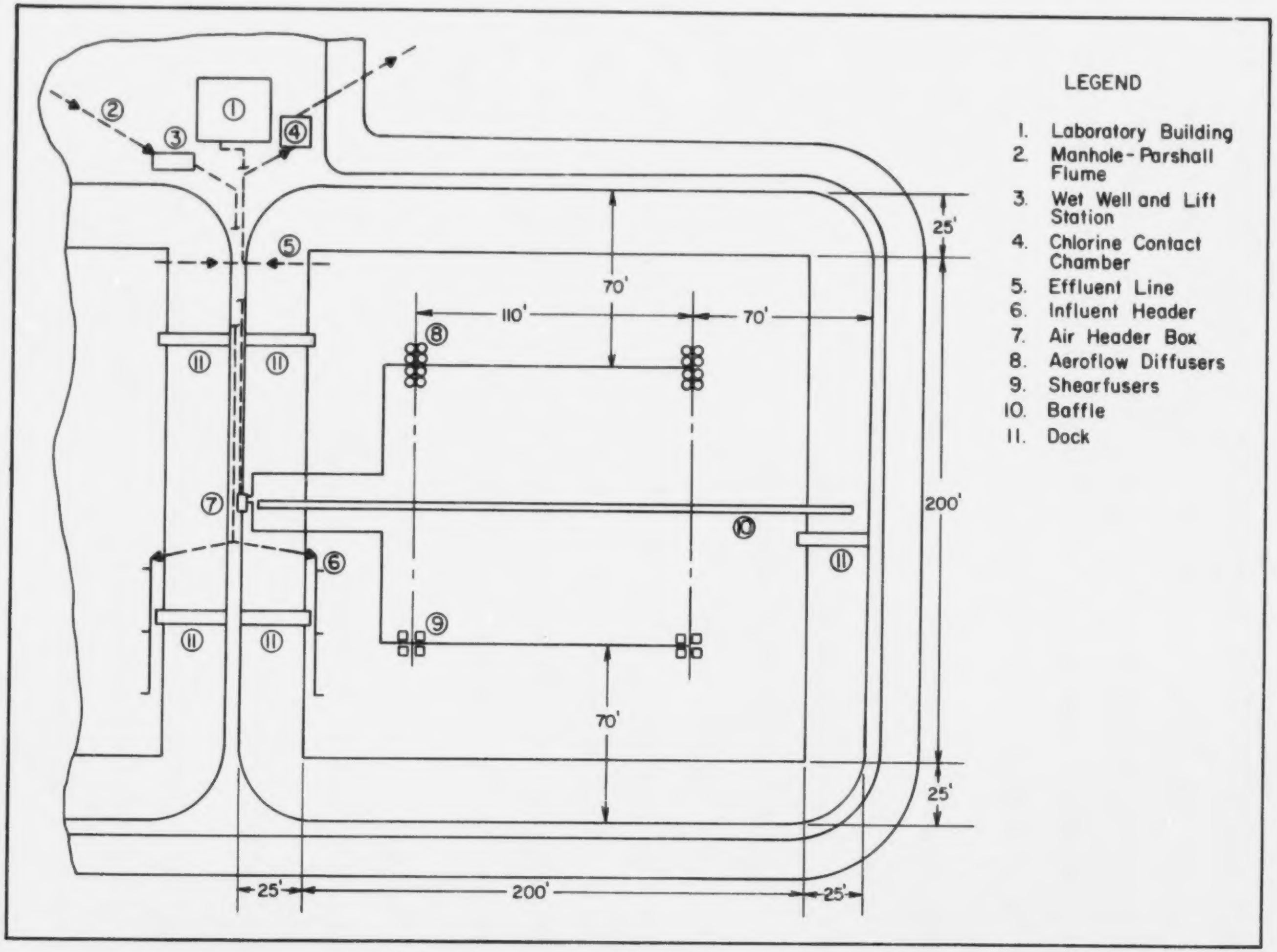
LEGEND
1. Laboratory Building
2. Manhole-Parshall Flume
3. Wet Well and Lift Station
4. Chlorine Contact Chamber
5. Effluent Line
6. Influent Header
7. Air Header Box
8. Aeroflow Diffusers
9. Shearfusers
10. Baffle
11. Dock
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
70'
110'
70'
70'
25'
200'
25'
25'
200'
25'

Figure 6. Plan view of Ft. Greely coarse bubble aerator installation.

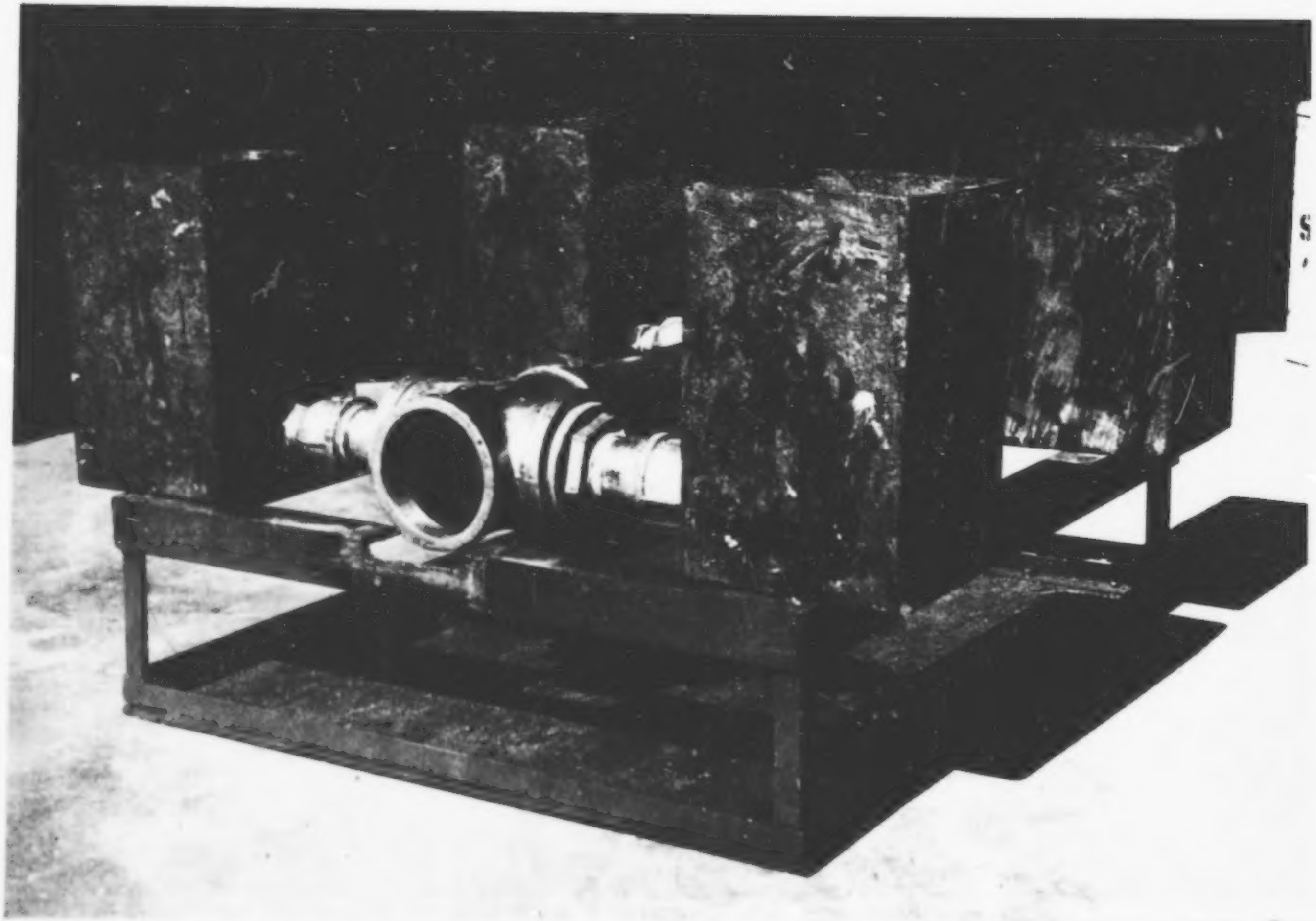

Figure 7. Chicago Pump Shearfuser cluster.

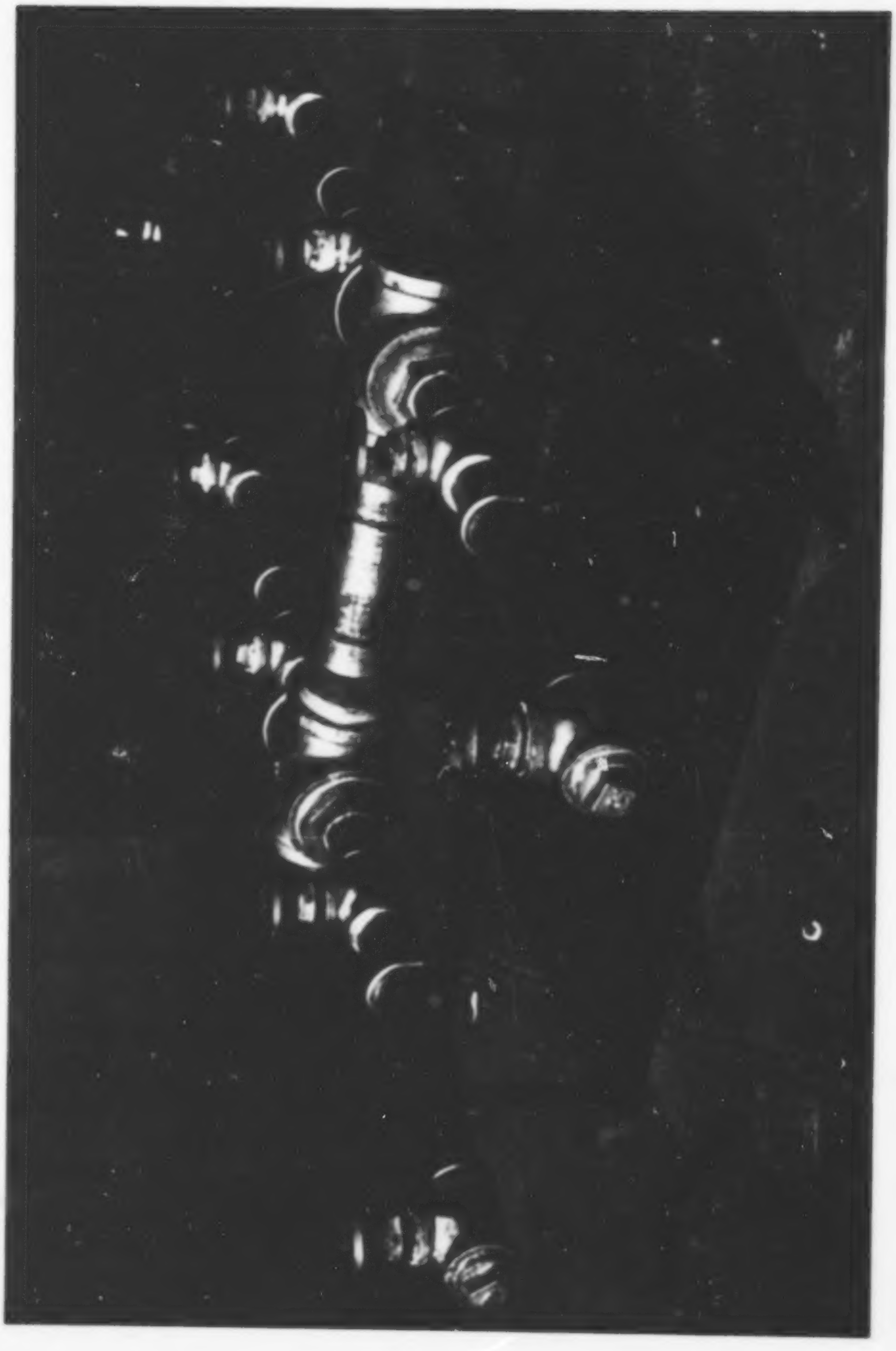

Figure 8. Aero-O-Flo non-clog diffuser cluster.

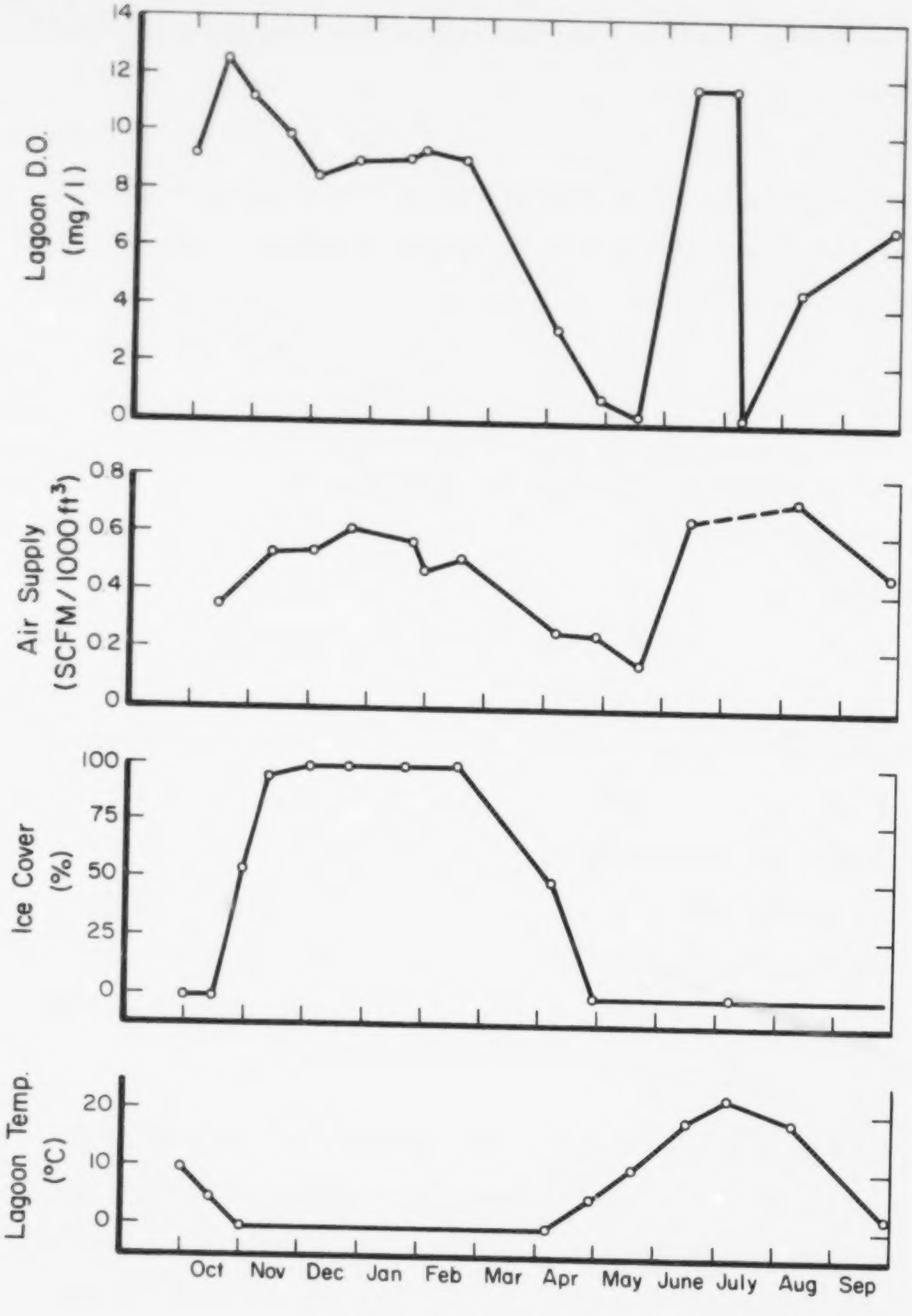

Figure 9. Ft. Greely fine bubble diffuser performance data.

the coarse bubble aerator side to reduce the discharge pressure of the compressors. The trend was detected three months after startup of the lagoon. Although the discharge pressure ranged around 0.63 kg/cm^2 in May, the air flow through the perforated tubing was so low that the lagoon became anaerobic. The tubing was cleaned with hydrochloric acid around the first of June. The cleaning plus algal activity accounts for the high DO levels during that month. Air flow data was not obtained in early July.

The low DO level which occurred in July was not due to low air flow but to bottom sludge turnover. This turnover was caused by heavy sludge layers which underwent increasing anaerobic action as the temperature increased until the resulting gas production caused the sludge to rise and disperse anaerobic products (organic acids, etc.) into the aerobic liquid above. The result was a drastic decline in algae and a great increase in DO uptake which reduced the lagoon DO level to zero. This lasted for a few days after which time the DO level began to increase. This phenomenon usually occurs each year after spring breakup in an aerated lagoon in which sludge accumulates with little decomposition over the winter months.

Figure 10 presents performance information for the coarse bubble diffuser side of the lagoon. The liquid temperature and ice cover were about the same as for the perforated tubing side except the ice cover did not reach 100 percent. Ice thickness in

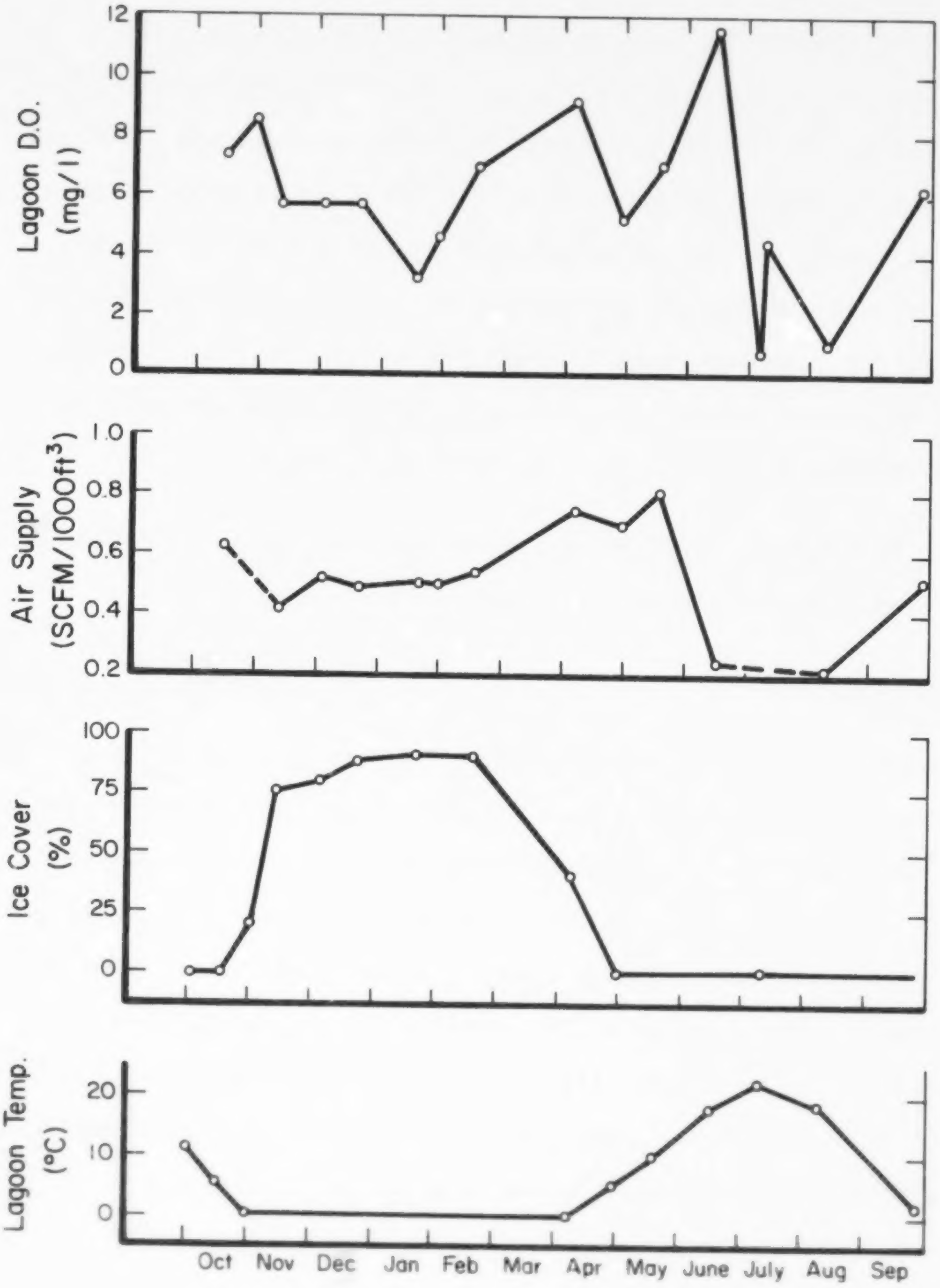

Figure 10. Ft. Greely coarse bubble diffuser performance data.

both lagoons was never more than a few inches. The air flow to the coarse bubble diffusers increased during the period of clogging of the perforated tubing. The low DO point in early June was again due to the sludge turnover phenomenon. The low DO point in August occurred when the first 16 lengths of perforated tubing at the influent were manually cleaned (reperforated) with sharpened screwdrivers. This method of cleaning reduced the pressure drop through the tubing to such a degree that the system required rebalancing of air flow between the coarse bubble diffusers and the perforated tubing.

Winter and summer aeration patterns for the coarse and fine bubble aerators are shown in Figures 11 through 14.

BOD and SS Removals

A summary of the lagoon performance is included in Table 4. The difference in detention times was due to an imbalance of flow to the two sides. Very little difference in removals between the coarse and fine bubble diffuser sides is indicated in spite of the difference in detention times and loadings. An exception was the higher effluent SS for the coarse bubble side effluent, presumably due to higher algae production for that side. A somewhat higher mixing rate caused by the course bubble diffusers may also have contributed to the higher SS values.

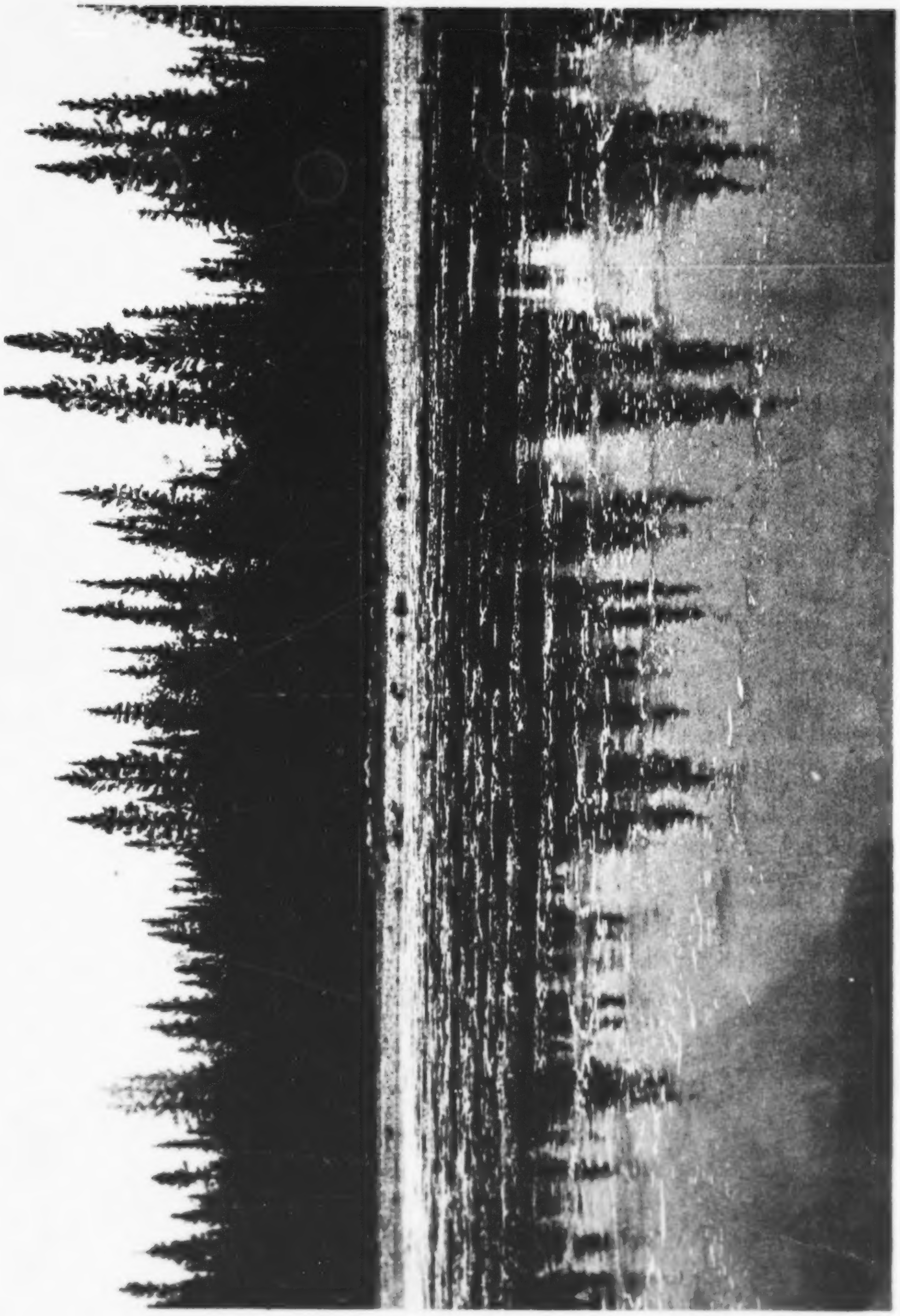

Figure 11. Fine bubble diffuser summer aeration pattern.

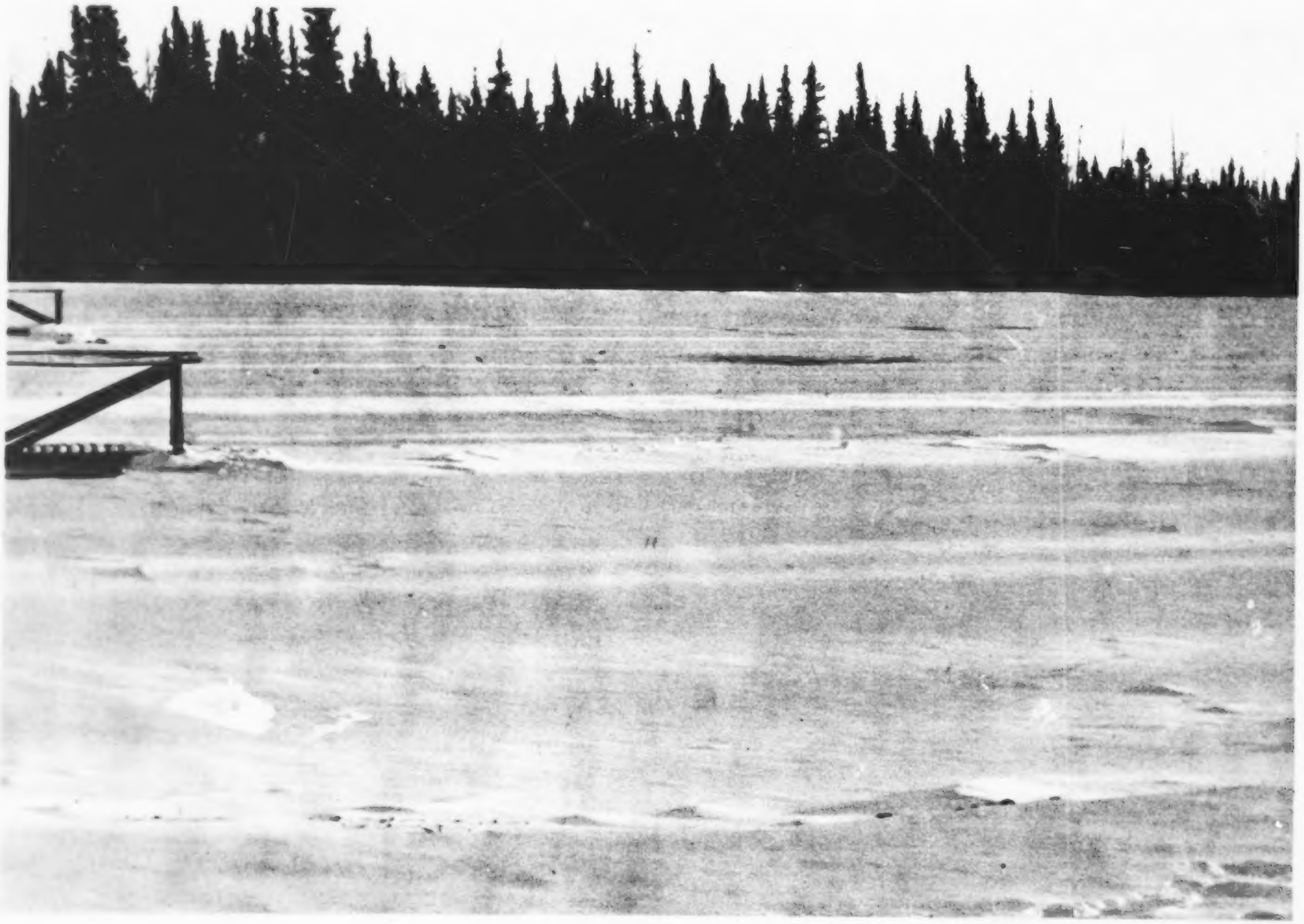

Figure 12. Fine bubble diffuser winter aeration pattern.

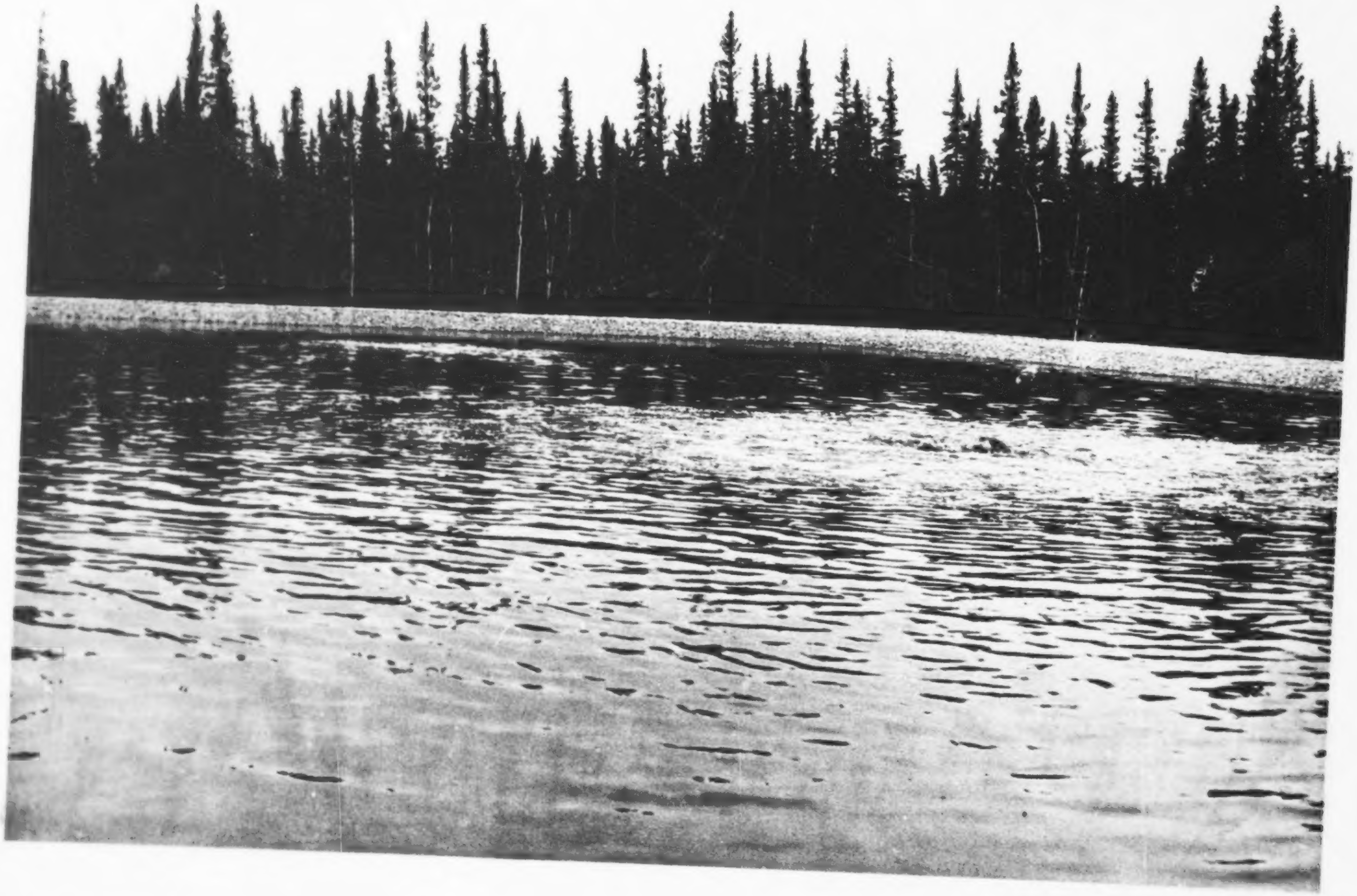

Figure 13. Coarse bubble diffuser summer aeration pattern.

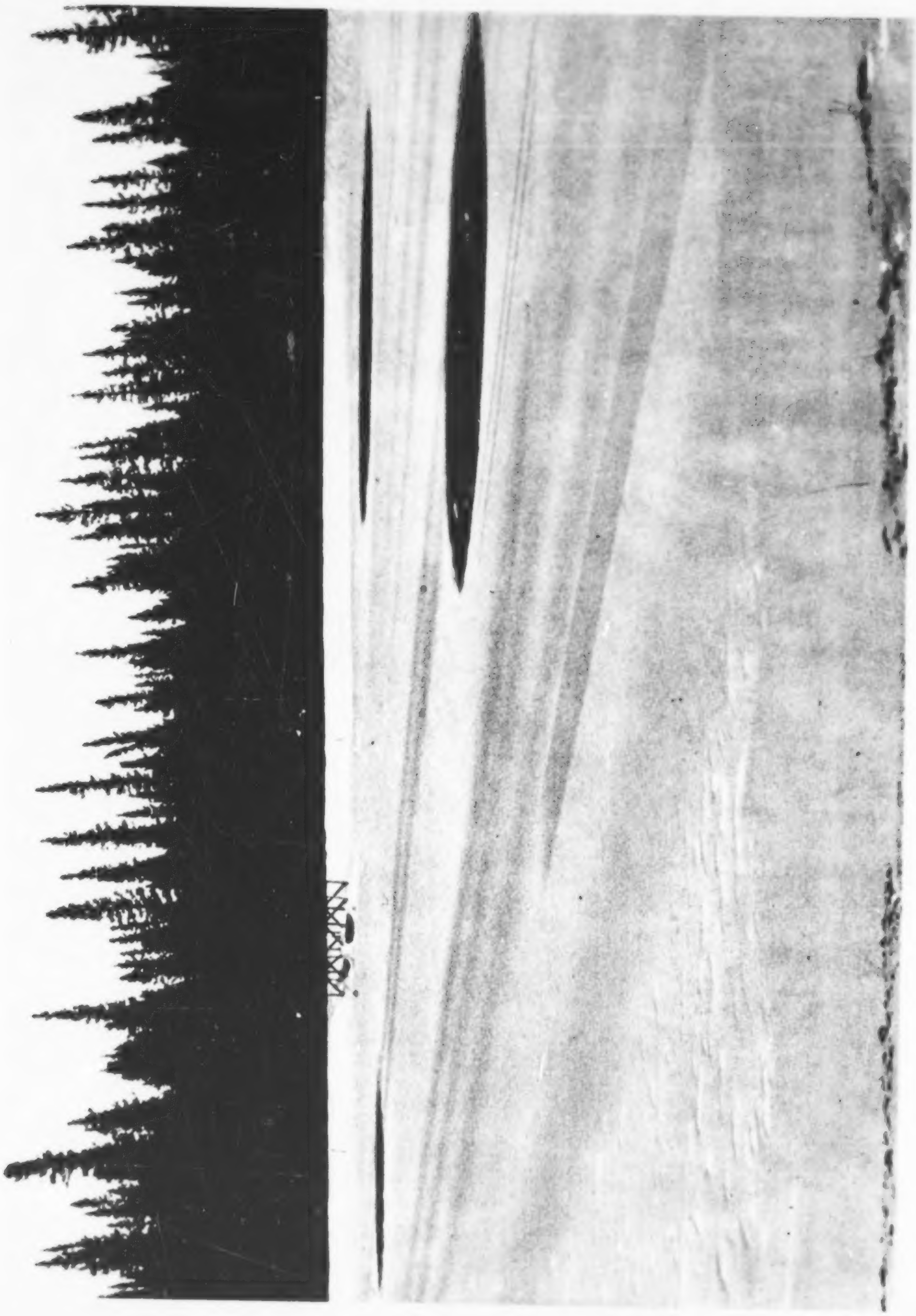

Figure 14. Coarse bubble diffuser winter aeration pattern.

Table 4. Performance Summary of Ft. Greely Aerated Lagoon

Period	Station	Detention Time (Days)		Loading (g BOD_5/m^3-day)		BOD_5				
		Per Cell	Accum.	Per Cell	Accum.	Mean	Stand Dev.*	Number Samples	Percent Removal Per Cell	Percent Removal Accum
Third and Fourth Years	Inf	-	-	-	-	190	137-274	9	-	-
	Coarse	26	26	7.3	7.3	39	24-72	9	-	80
	Fine	39	39	4.9	4.9	37	27-56	9	-	81
Third Year Winter	Inf	-	-	-	-	189	164-204	6	-	-
	Coarse	25	25	7.6	7.6	37	25-48	6	-	80
	Fine	38	38	5.0	5.0	33	27-39	6	-	82
Fourth Year Summer	Inf	-	-	-	-	192	137-274	3	-	-
	Coarse	29	29	6.6	6.6	43	24-72	3	-	78
	Fine	43	43	4.5	4.5	45	34-56	3	-	77

(Continued)

Table 4. Continued

Period	Station	COD					SS				
		Mean	Stand Dev.*	Number Samples	Percent Removal		Mean	Stand Dev.*	Number Samples	Percent Removal	
					Per Cell	Accum.				Per Cell	Accum
Third and Fourth Years	Inf	358	61	15	-	-	153	29	15	-	-
	Coarse	125	26	15	-	65	47	28	15	-	69
	Fine	120	15	15	-	67	41	15	15	-	73
Third Year Winter	Inf	342	254-407	9	-	-	146	110-170	9	-	-
	Coarse	117	102-128	9	-	66	38	19-51	9	-	74
	Fine	114	100-127	9	-	67	30	26-49	9	-	75
Fourth Year Summer	Inf	352	276-424	4	-	-	161	97-218	4	-	-
	Coarse	143	97-211	4	-	59	73	42-141	4	-	55
	Fine	138	125-159	4	-	61	57	33-78	4	-	65

* The range is shown where the number of samples collected was less than 10.

Sludge Accumulation

Sludge depth measurements were made on the coarse bubble side of the Ft. Greely lagoon in July 1971 while the lagoon was drained for modification. Sludge accumulation over the perforated tubing near the influent averaged about 50 cm along the influent manifold and tapered to a depth of 5 cm approximately 15 m from the influent edge of the lagoon. The remainder of cell 1 was approximately 75% covered with 3 - 5 cm of sludge. The second cell was approximately 50% covered with 3 - 5 cm of sludge.

Sludge core samples were taken near the influent manifold at various times during the project (Table 5). The core samples appeared to be preserved essentially as deposited and were well compacted which may account for the relatively high percent solids.

Two temperature probes were placed in the sludge near the influent manifold at approximate depths of 18 cm and 48 cm. The sludge depth at this point was 50 cm. The sludge temperatures recorded along with the lagoon liquid temperature are shown in Figure 15. The probe at 18 cm in depth ceased functioning after the May measurement. The high temperature recorded in May is probably due to high influent temperatures which remained at 20°C or greater throughout the project. Sufficient gas had accumulated to cause sludge turnover to occur about July 10.

Table 5. Ft. Greely Aerated Lagoon Sludge Analysis

	Near Influent - Cell 1									Near Effluent Cell 1			Near Effluent Cell 2		
	Bottom			Middle			Top								
Date	% Total Solids	% Volatile	pH	% Total Solids	% Volatile	pH	% Total Solids	% Volatile	pH	% Total Solids	% Volatile	pH	% Total Solids	% Volatile	pH
12/21/71	6	67	5.6	19	47	5.9	21	58	6.3	-	-	-	-	-	-
5/19/72	-	-	-	31	40	-	22	50	-	-	-	-	-	-	-
6/16/72	-	-	-	5	54	-	17	9	-	1	69	-	37	10	-
11/30/72	20	40	5.6	-	-	-	53	5	6.0	31	19	-	67	3	-

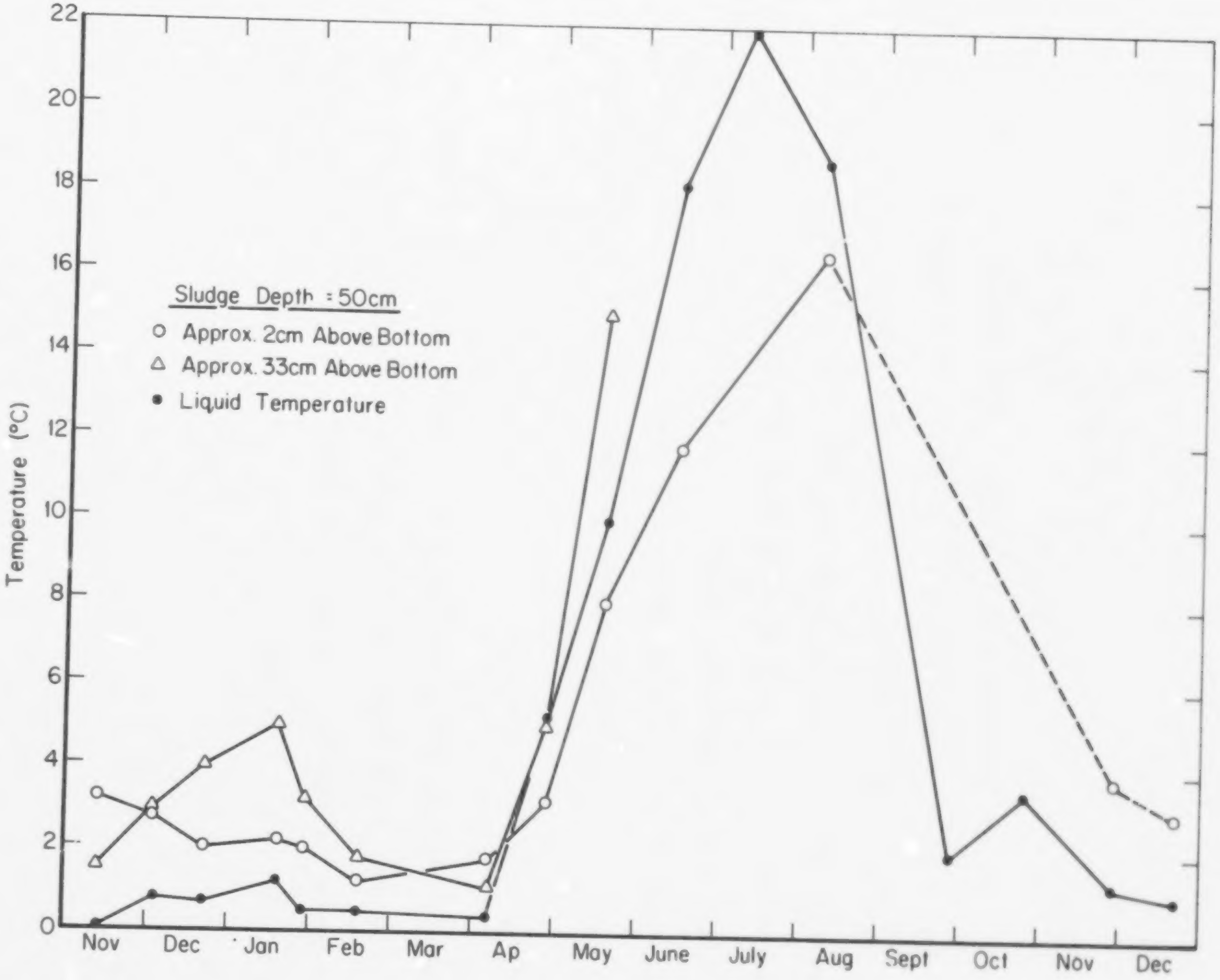

Figure 15. Ft. Greely aerated lagoon sludge and liquid temperature, 1971-1972.

As expected, the sludge temperatures lag the liquid temperatures and do not peak as high in the summer. The deeper sludge did not reach a sufficiently high temperature for anaerobic decomposition until late May and June, even with the high temperature influent at Ft. Greely. The period of higher temperatures lasts for 3 or 4 months at the most.

Algae Growth

The variation of suspended solids and algae during the summer season for the Ft. Greely lagoon is shown in Figure 16. These values are for the coarse bubble side effluent and are very similar to the fine bubble side values. In both cases the algae levels built up very high during June and decreased sharply after the bottom sludge turnover which occurred in early July. As may be expected, the filtered BOD levels show that good effluent quality can be obtained if algae removal can be accomplished.

Nutrients

Ft. Greely lagoon nutrient removals follow a pattern similar to those for the EAFB Experimental lagoon. Winter NH_3-N and T-N values show no change through the lagoon and summer operation shows significant removal (Table 6). The phosphorus data shows no net reduction.

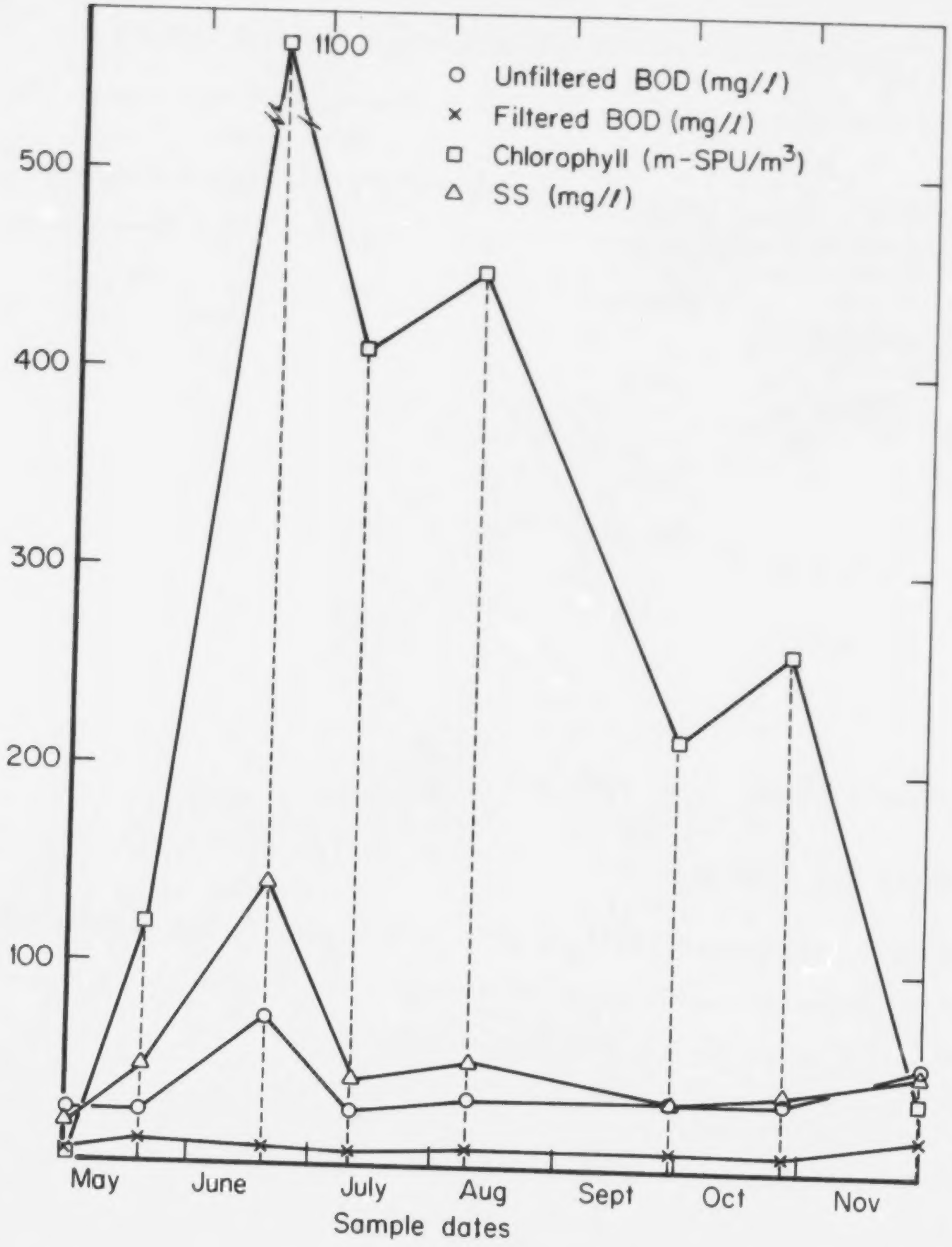

Figure 16. Ft. Greely aerated lagoon BOD, chlorophyll and suspended solids vs. summer sampling dates.

Table 6. Ft. Greely Lagoon Nutrient Removal Summary

Period	Station	Nutrients			
		NH_3-N	T-N	O-P	T-P
Winter	Inf	15	22	6	9
	Coarse	16	22	9	9
% Removal		(-7)	0	(-50)	0
	Fine	16	21	8	9
% Removal		(-7)	5	(-33)	0
Summer	Inf	16	21	3	7
	Coarse	10	14	7	8
% Removal		38	33	(-133)	(-14)
	Fine	12	16	7	8
% Removal		25	24	(-133)	(-14)

NORTHWAY LAGOON

Lagoon Description

The Northway Lagoon consists of a wood crib structure with vertical sides and sealed with bentonite. Dimensions are 12.8 m X 16.5 m X 2.3 m for an operating volume of 480 m^3.

A longitudinal baffle splits the lagoon into two equal cells, each 6.4 m wide. Feed consisted of domestic sewage from the Federal Aviation Administration (FAA) station, comprising 14 family units. The feed temperatures were estimated to vary from 2 - 24°C.

The lagoon was placed in operation during September 1965 using the perforated plastic aeration tubing. In September 1970, one Air Gun aerator (Aero-Hydraulic Corp., Montreal, Quebec) was installed in each cell. These air guns consist of a 30.5 cm diameter by 1.5 m long submerged vertical plastic pipe with an air chamber at the lower end. Air is pumped into the chamber and builds up until released by a siphoning effect through the tube. The rising air bubble "piston" draws in water from holes in the pipe located just above the air chamber and a pumping action occurs. Air gun aerators are designed for use in deeper lagoons (4 - 5 m) and are designed to provide mixing as well as oxygenation.

The air gun aerators had been furnished by the manufacturer on a loan basis and had to be returned during the summer of 1972. Rather than attempt to rejuvenate the perforated tubing, pipe stub nozzles were placed in the lagoon and connected to the air headers. A check in October 1972 indicated the DO levels in the lagoon to be near saturation, and the total detention time to be about 25 days.

BOD and SS Removals

Overall BOD removal from the third through the eighth year was approximately 86 percent which compared very well with the other lagoons investigated (Table 7). A comparison of the third and

Table 7. Performance Summary of Northway Aerated Lagoon

		Detention Time (Days)		Loading ($g\ BOD_5/m^3$-day)		BOD_5				
									Percent Removal	
Period	Station	Per Cell	Accum.	Per Cell	Accum.	Mean	Stand Dev.*	Number Samples	Per Cell	Accum
Third through Eighth Years	Inf	-	-	-	-	261	73	11	-	-
	Cell -1	20.0	20.0	13.1	13.1	51	17	13	81	81
	-2	20.0	40.0	2.6	6.5	37	15	19	27	86
Third Year	Inf	-	-	-	-	238	140-330	4	-	-
	Cell -1	22.0	22.0	10.8	10.8	56	34-82	5	76	76
	-2	22.0	44.0	2.6	5.4	30+	13-67	7	47	87
Eighth Year	Inf	-	-	-	-	213	198-228	2	-	-
	Cell -1	14.5	14.5	14.7	14.7	34	30-38	2	84	84
	-2	14.5	29.0	2.3	7.3	31	19-52	6	9	85
Third through Eighth Year Winter Period	Inf	-	-	-	-	297	195-380	6	-	-
	Cell -1	12.3	12.3	24.2	24.2	60	42-82	7	80	80
	-2	7.7	20	7.8	14.9	49	24-67	8	18	84

(Continued)

Table 7. Continued

Period	Station	COD					SS				
		Mean	Stand Dev.*	Number Samples	Percent Removal		Mean	Stand Dev.*	Number Samples	Percent Removal	
					Per Cell	Accum.				Per Cell	Accum
Third Through Eighth Years	Inf	479	130	10	-	-	206	130-353	9	-	-
	Cell -1	150+	26	10	69	69	61+	49-136	9	70	70
	-2	136+	32	14	9	72	39+	17	13	37	81
Third Year	Inf	405	237-542	3	-	-	164	131-196	2	-	-
	Cell -1	208	97-406	3	49	49	104	71-136	2	37	37
	-2	168	118-231	3	19	58	30	25-34	2	72	82
Eighth Year	Inf	502	484-520	2	-	-	151	130-172	2	-	-
	Cell -1	158	150-165	2	69	69	53	50-56	2	65	65
	-2	116	76-146	6	26	77	29+	18-66	6	45	81
Third through Eighth Years Winter Period	Inf	469	237-691	6	-	-	233	131-353	6	-	-
	Cell -1	150+	120-406	6	68	68	63+	49-136	6	73	73
	-2	147+	118-231	7	2	69	47+	25-93	7	25	80

* The range is shown where the number of samples collected is less than ten.

+ Adjusted from probability plot.

eighth years performance showed little aging effect over this period. Detention time for this period averaged 40 days.

Bottom Sludge

Analysis of sludge samples from the Northway Lagoon are shown in Table 8.

In June 1967 and March 1971, sludge core samples were examined. The sludge appeared to be preserved exactly as deposited. However, in August 1967 and May 1968, bottom samples had a definite black appearance and the physical characteristics of partially digested sludge. Methane production apparently occurred during the summer of 1967 causing the sludge location to shift between the August 1967 and May 1968 sampling dates. The maximum bottom sludge temperature recorded at Northway was 19°C.

Samples taken at Northway during March 1970 indicate an average sludge accumulation of approximately 15 cm in the first cell and approximately 8 cm in the second cell. This indicates an accumulation rate of 2.5 cm per year for 4.5 years or approximately 255 liters per 1000 people per day, which is in the low range of observed rates for stabilization ponds (Clark et al., 1970). Due to compaction, consolidation, and digestion the long range accumulation may be less.

Table 8. Northway Aerated Lagoon Sludge Analysis

	Cell 1				Cell 2			
Date	% Total Solids	% Volatile	pH	COD mg/g/ Dry Wt.	% Total Solids	% Volatile	pH	COD mg/q Dry Wt.
03/30/70	13	44	6.8	92	-	-	-	-
03/17/71	9	44	-	54	42	7	-	44
05/24/72	12	67	-	110	4	63	-	34
10/06/72	12	45	7.3	95	14	17	7.6	59
Ave	12	50	-	88	20	29	-	46

In late March 1970, a 5 cm diameter bottom sludge core sample from the first cell, Northway lagoon, was sectioned and analyzed for fecal indicator bacteria (Clark et al. 1970). The 23 cm core was cut in three sections as follows: 7.6 cm bottom, 13 cm middle, and 2.5 cm top layer.

MPN counts on a per wet gram basis were as follows:

	No. of Organisms x 10^3		
	TOP	MID	BOTTOM
Presumptive total coliform	4.9	49	22.1
Confirmed total coliform	3.3	13	13
Fecal Coliform	2.4	4.9	3.3
Presumptive enterococci	13	221	172
Confirmed enterococci	13	221	172

It appears that the sludge located deeper in the core has a more favorable environment for concentration and preservation of fecal organisms even though the sludge temperature was less than 1°C. Four additional sludge cores were taken. Three had pH readings of 7.0 to 7.5 while only one had a pH of 5 to 6. The moisture content averaged 90 percent.

Results from 2.5 cm diameter bottom sludge cores obtained from both cells during March 1971 were as follows.

MPN counts on a per wet gram basis were:

	No. of Organisms x 10^3	
	Cell 1	Cell 2
Presumptive total coliform	130	1410
Confirmed total coliform	79	140
Fecal coliforms	3.3	insufficient media
Presumptive enterococci	130	94
Confirmed enterococci	33	94
Confirmed enterococci (Counts/mg. volatile solids)	83	2300

As compared to 1970 the coliforms appear to be composed of a smaller fraction of fecal coliforms. Also the enterococci level appears to be much lower. The 1971 results indicate that the sludge in cell 2 is well digested but still harbors many enteric bacteria.

Nutrients

Nutrient removals for the Northway lagoon show essentially the same results as the EAFB Experimental and Ft. Greely lagoons (Table 9). The phosphorus was not affected and the total nitrogen removal was insignificant.

Table 9. Northway aerated lagoon nutrient removal summary

		NH_3-N	T-N	O-P	T-P
Northway Overall	Feed	19	35	7	12
	Cell 1	30	33	12	13
	Cell 2	30	32	12	12

EAGLE RIVER LAGOON

Lagoon Description

The Eagle River Lagoon had two equal size principal cells which could be operated in series or parallel. Each principal cell measured 30 m X 12 m at the base and was divided into two smaller cells by a baffle below the liquid surface. Total lagoon volume was 9,500 m^3 at an operating depth of 4.6 m. The lagoon was constructed of an earthen dike with a side slope ratio of 2:1 and a liner of butyl rubber. Aeration was provided by fine bubble type Hydro-Ceramic diffusers which consist of PVC tube with porous ceramic stones inserted 0.3 m apart. Each stone provides about 0.6 cm^2 of surface area.

The lagoon treated domestic waste and also served two laundry facilities which contributed a significant portion of the load. Feed temperatures ranged from around 5°C in the winter, to a maximum of 15°C during the warmer months.

Operation Problems

Since the lagoon began operation, the aeration system has been plagued with problems which have contributed to the poor performance. Most of the problems occurred when the diffusers became clogged and high pressures developed in the system. The glued joints of the PVC piping have tended to pull apart or break and a number of the porous stones have blown out. The system has been described as fragile and unreliable (R. Hutson, personal communication, 1976). Failures which occur in the winter cannot be repaired until summer.

The lagoon was placed in operation in the late fall of 1971 with only one side in operation. The second side was placed in operation in the spring of 1972. Blower pressures were at 0.56 kg/cm^2 at startup and gradually climbed to 0.91 kg/cm^2 which forced draining of that cell in July 1972 for inspection (Mike Pollen, Personal Communication, 1972). On inspection the ceramic diffusers were found to be clogged with a matting of lint, hair and solids.

Cutting a cross-section of the diffuser showed small particles of lint and hair imbedded in the diffuser to a depth of approximately 3.2 mm. Direct applications of concentrated hydrochloric acid and scraping removed a large portion of the material but deeply imbedded material required cleaning of individual pores. The material was felt to have been forced into the diffuser when

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the blowers were shut off for maintenance purposes, allowing water to back up in the aeration system.

The diffusers were cleaned in the field by brushing and washing with mild detergent soap. Blower pressures were at about 0.60 kg/cm^2 in October 1972, and the system was performing satisfactorily. By June, the pressure had begun to build up again, although not to the levels previously experienced. Visual observation had shown the aeration pattern was obviously deteriorating. The diffusers were cleaned at the end of June by introducing toluene at a rate of 34 g/m and hydrochloric acid at a rate of 189 g/m at the instruction of the diffuser manufacturer. The hydrochloric acid cleaning was effective since a good aeration pattern was established and the blower pressure dropped back to 0.56 kg/cm^2. The toluene cleaning was ineffective.

At this time the lagoon was drained and sludge deposits were found as shown in Figure 17. The intensive aeration provided in the first cell due to the high depth vs width ratio of the lagoon forced sludge carryover to the other side of the baffle. Sludge deposition occurred in a less intensive aeration area near the effluent discharge pipe. The sludge layer was not compacted (high percentage of water) and the level was at the bottom of the effluent pipe or at 0.45 m.

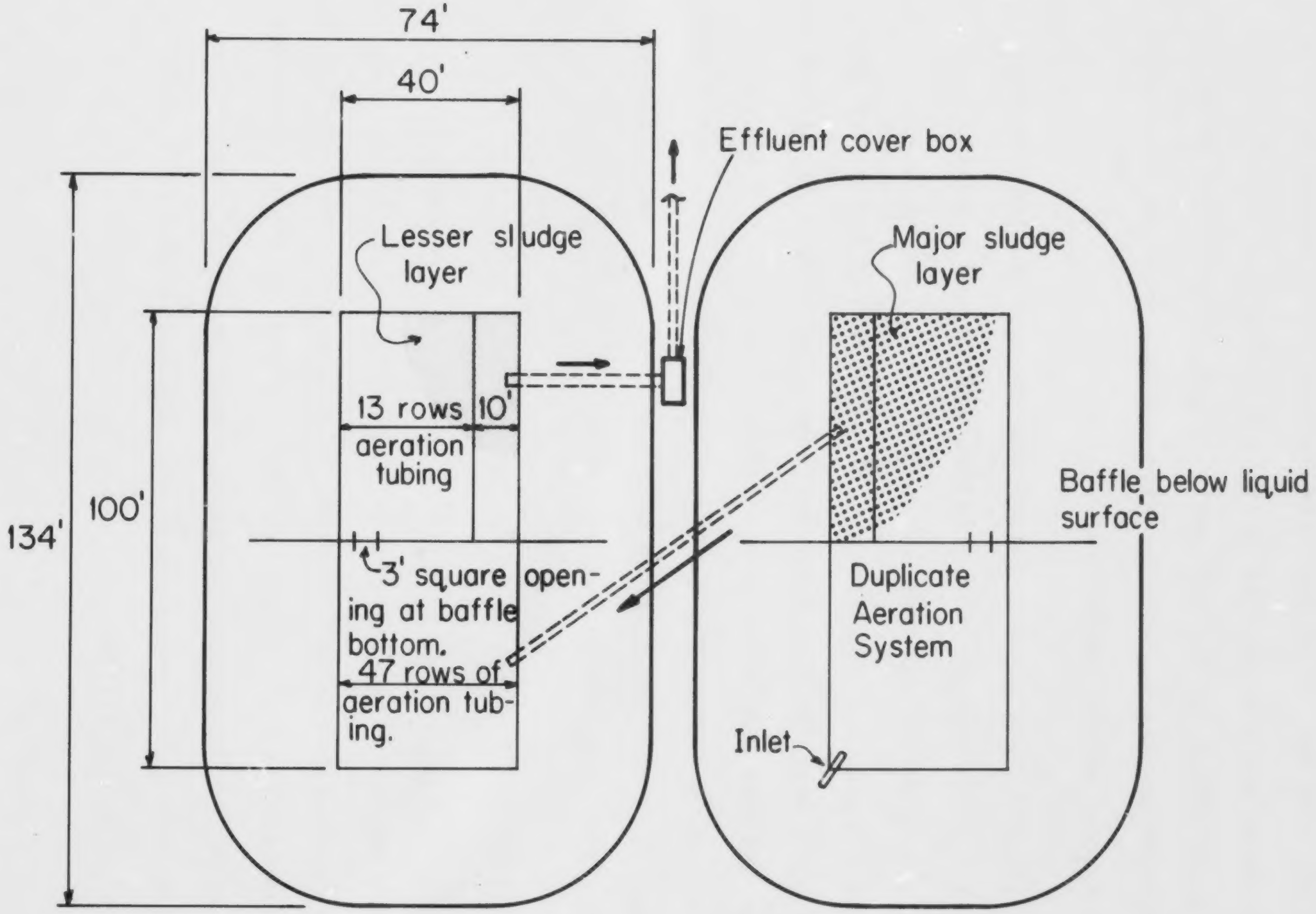
74'
40'
Effluent cover box
Lesser sludge layer
Major sludge layer
13 rows aeration tubing
10'
134'
100'
Baffle below liquid surface
3' square opening at baffle bottom.
47 rows of aeration tubing.
Duplicate Aeration System
Inlet

Figure 17. Eagle River lagoon sludge blanket.

In October, 1973 the flow pattern was changed from series to parallel. In May, 1974 the flow pattern was changed back to series with the result that very high suspended solids levels were experienced in the effluent. These solids were apparently resuspended by the relatively higher flows through the lagoon cells during series operations.

One principal cell of the lagoon was drained during the summer of 1974 for repairs to the aeration system and a portion of the ceramic diffusers were replaced with Aer-O-Flow aerators. Similar repairs and replacement of aerators in the other principal cell were completed in the summer of 1975. Initially the cap on the new diffusers had a tendency to blow off at relatively high air pressures. The manufacturer provided redesigned diffusers for replacement which have operated very well (Richard Hutson, Personal Communication, 1976).

BOD and SS Removals

A summary of operating results beginning in September 1972 through March 1976 are presented in Table 10 and Figure 18. The worst performance results occurred during the summer months and were apparently due to four causes: algae production, changing from parallel to series operation, performance of necessary repairs during the warm summer months, and dumping of septic tank wastes into the system.

Table 10. Eagle River Aerated Lagoon Performance Summary

Period	Station	Detention Time (Days)	Loading (g BOD_5/m^3-day)		BOD_5			
			Per Cell	Accum	Mean	Stand Dev.*	Number Samples	Percent Removal
Second Year Overall Series Operation	Inf.	-	-	-	185	79	97	-
	Eff.	18.2	-	10.2	38	20	95	79
Second Year Winter Series Operation	Inf	-	-	-	142	51	34	-
	Eff	16.6	-	8.6	29	8	38	80
Second Year Summer Series Operation	Inf	-	-	-	213	89	40	-
	Eff	19.4	-	11.0	49	27	37	77
Third Year Winter Parallel Operation	Inf	-	-	-	149	45	21	-
	Eff	17.8	-	8.4	50	11	21	66
Third Year Summer Single Cell Operation	Inf	-	-	-	124	86-162	6	-
	Eff	9.2	-	13.5	55	25-78	6	56
Fourth Year Winter Series Operation	Inf	-	-	-	158	47	16	-
	Eff	17.3	-	9.1	36	16	12	77
Fourth Year Summer Single Cell Operation	Inf	-	-	-	151	59	14	-
	Eff	6.9	-	21.9	78	25	14	48
Fifth Year Winter Series Operation	Inf	-	-	-	191	113	12	-
	Eff	10.9	-	17.5	41	13	12	79

(Continued)

Table 10. Continued

Period	Station	COD Mean	COD Stand Dev.*	COD Number Samples	COD Percent Removal	SS Mean	SS Stand Dev*	SS Number Samples	SS Percent Removal
Second Year Overall Series Operation	Inf	507	208	49	-	237	113	112	-
	Eff	149	52	51	71	56	38	113	76
Second Year Winter Series Operation	Inf	350	103	17	-	149	71	36	-
	Eff	113	13	18	68	30	7	41	80
Second Year Summer Series Operation	Inf	587	236	19	-	292	97	46	-
	Eff	195	53	20	67	88	41	45	70
Third Year Winter Parallel Operation	Inf	492	148	20	-	198	83	21	-
	Eff	214	22	21	57	71	14	20	64
Third Year summer Single Cell Operation	Inf	436	337-521	7	-	197	128-284	7	-
	Eff	314	237-345	6	28	150	98-187	6	24
Fourth Year Winter Series Operation	Inf	582	193	16	-	226	75	16	-
	Eff	190	52	17	67	60	15	18	73
Fourth Year Summer Single Cell Operation	Inf	482	212	14	-	196	112	14	-
	Eff	443	129	14	8	252	107	14	(- 29)
Fifth Year Winter Series Operation	Inf	444	201	13	-	141	55	15	-
	Eff	192	43	13	57	59	19	13	65

* The range is shown where the number of samples collected is less than ten.

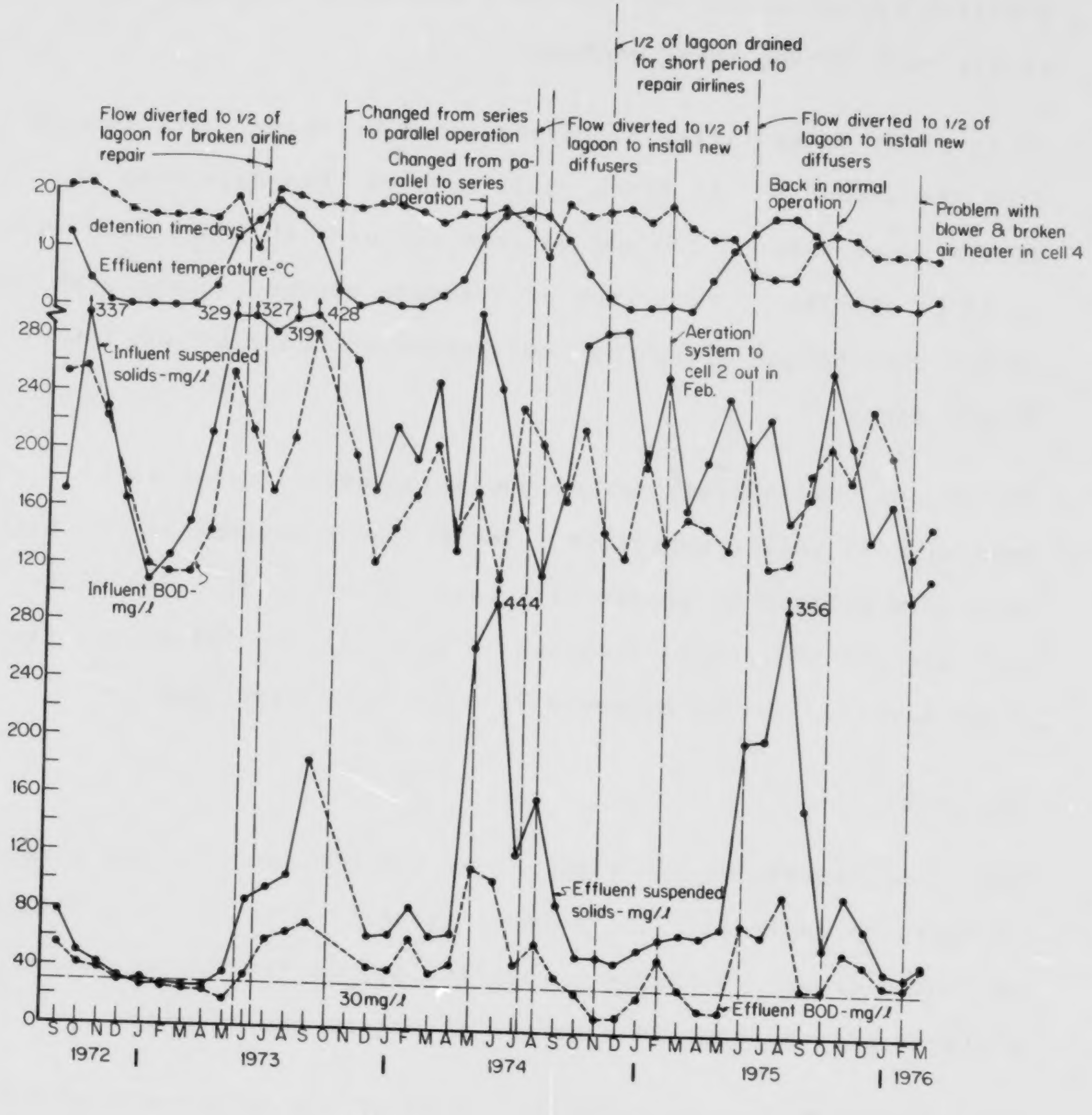

Figure 18. Eagle River lagoon operating results.

A comparison of various phases of the lagoon operation indicates that series operation is superior to parallel operation during winter months (Table 10). A comparison of summer series and parallel operation was not possible because of the need to do repair work during these months.

There seems to be little difference in BOD removal efficiencies from the second to the fifth year; however, the data does indicate a decrease in COD and SS removals over this period. This could be attributed to a lack of adequate sludge storage with the result that bottom sludge is resuspended and carried out the effluent pipe.

The second year overall series operation was selected as a typical full year's operation. The effluent parameters for that year were plotted on probability paper (Figure 19). The plots indicate the BOD and SS exceeded 30 mg/l 55% and 70% of the time, respectively. The SS exceeded 70 mg/l 30% of the time.

Coliforms

The effectiveness of the Eagle River disinfection contact chamber is shown in Table 11. The chamber is baffled so that the length of liquid travel is 12.2 m. Chlorine gas is fed to the lagoon effluent stream about 20 m before it enters the chamber.

The arithmetic mean and geometric mean of the coliform counts are both shown. The chamber is most effective at nominal contact

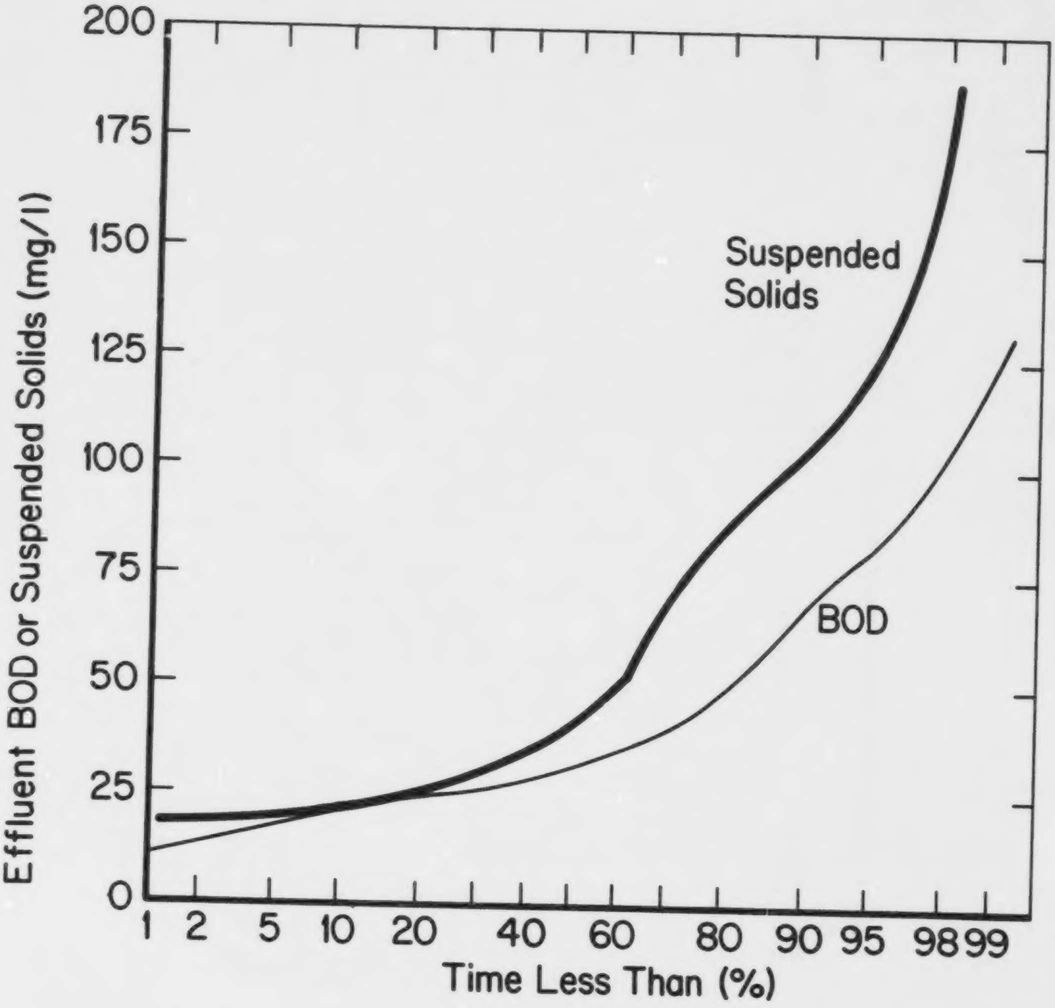

Figure 19. Eagle River aerated lagoon effluent BOD and suspended solids variability.

Table 11. Eagle River aerated Lagoon Disinfection Summary

Period	Nominal Contact Time (Min)	Chlorine Residual (mg/1)	Total Coliforms per 100 ml (Avg)*	Fecal Coliforms per 100 ml (Avg)*	Number of samples
Second Year Winter 11/10/72-3/28/73	92	1.5	1525 (221)	-	4
Second Year Summer 5/10/73-9/26/73	107	1.0	2037 (516)	-	19
Third Year Winter 12/12/73-2/28/74	98	1.0	922 (302)	0.4 (1)	17
Third Year Summer 7/25/74-9/6/74	101	1.0	790 (314)	16.4 (9)	10
Fourth Year Winter 11/21/74-3/25/75	95	0.8	6,100 (1938)	37.6 (12)	28
Fourth Year Summer 6/4/75-9/4/75	76	1.2	60,890 (8446)	744 (39)	19
Fifth Year Winter 12/2/75-2/25/76	60	1.9	27,800 (20,275)	419 (139)	26

* Value in parentheses = geometric mean

times greater than 90 minutes with fecal coliforms exhibiting less resistance to chlorination than total coliforms.

EIELSON AIR FORCE BASE FULL SCALE LAGOON

Lagoon Description

The Eielson Air Force Base Lagoon is similar in design to the Ft. Greely Lagoon except that aeration is provided by Kenics Aerators. The lagoon had two principal cells 30 m X 12 m at the base which were equally divided into two smaller cells by a baffle below the surface of the water. The total lagoon volume was 56,030 m^3 at an operating depth of 3 m. A chlorine contact chamber of 81.4 m^3 provided a contact time of 30 min. at 3,900 cu m/day flow. The lagoon receives effluent from the EAFB primary treatment plant.

Operation Problems

During startup in November, 1973, the lagoon was filled with lake water for testing purposes. When the aeration system began operation, the combination of cold water and cold air resulted in ice buildup on the aerators. The aerators, which were connected to flexible air lines, plus the small concrete pads on which they were mounted floated to the surface. The lagoon was drained and the aerators returned to their original position. The introduction of warm wastewater melted the ice and the aeration system has since performed satisfactorily with no problems (Jim O'Neil, Personal Communication, 1976).

The lagoon liner was brought to the top of the dike with no gravel or rip rap covering. Tearing problems from ice movement have not occurred in the main lagoon; however, patching of a number of holes was necessary in the chlorine contact chamber which was constructed in the same fashion as the main lagoon. The holes were made by ice movement the previous winter. Separation at the seams of the main lagoon liner did occur during the first winter's operation and these were repaired during May and June, 1974. The liner manufacturer attributed the separations to waste petroleum products in the wastewater. An alternate cause may have been installation of the liner without sufficient slack to account for contraction at colder temperatures.

BOD and SS Removals

Operating performance of the lagoon from January, 1974 through April 1976 is presented in Figure 20. The results show evidence of aging by the lagoon as the effluent quality for 1975-76 is generally lower than for 1974. The highest effluent SS occurred in June, 1974 when one-half of the lagoon was taken out of operation for repairs. Dumping of large amounts of septic tank sludge apparently caused a high effluent BOD in September 1974.

Because of the frequency of changes in the lagoon operation which occurred during the study period, a good comparison of series and parallel operation was not possible (Table 12). The series operation during the first summer appears to have improved the

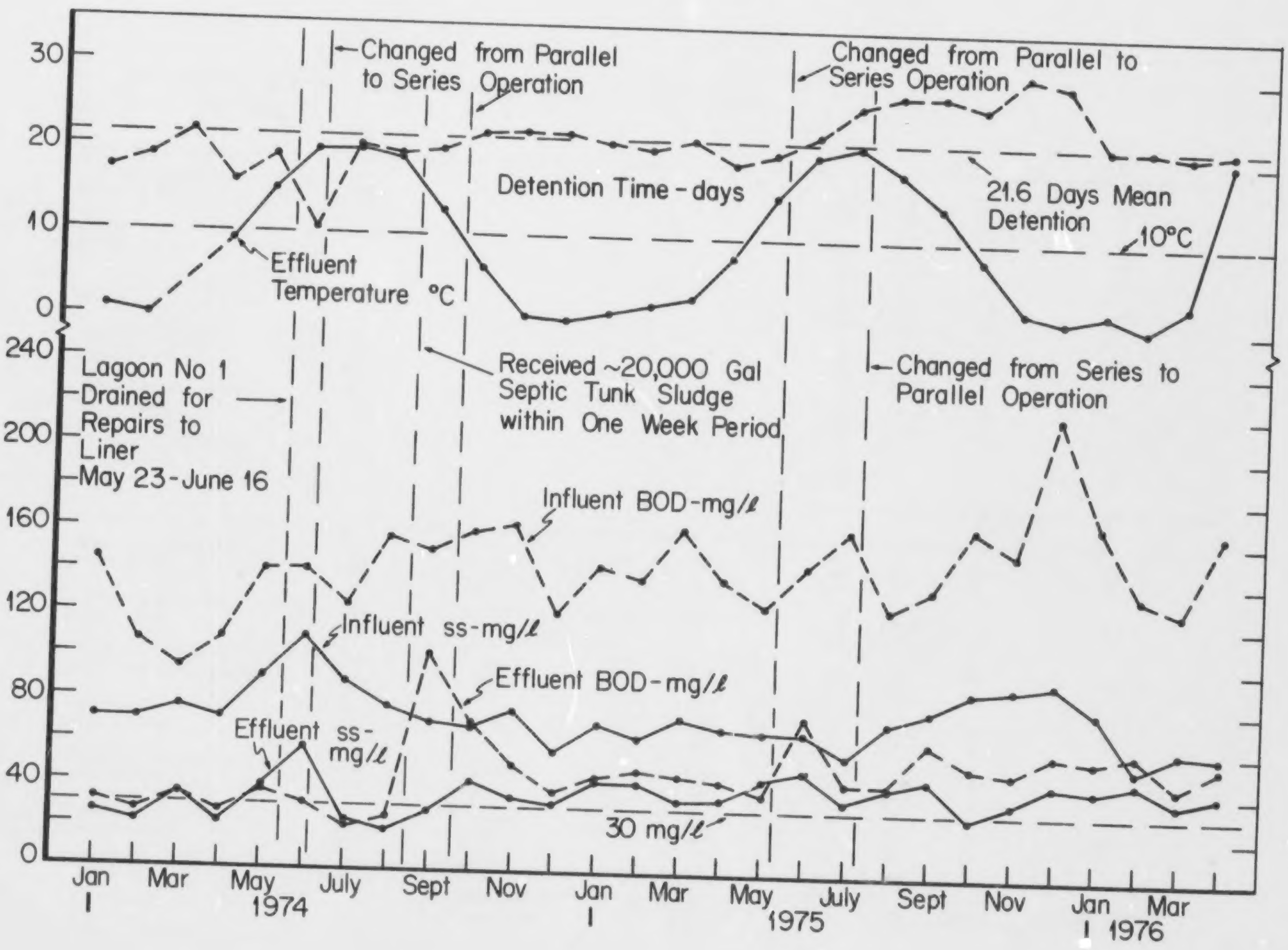

Figure 20. EAFB full scale lagoon operating results.

Table 12. Performance Summary of EAFB Full Scale Lagoon*

Period	Station	Detention Time (Days)	Loading (g BOD_5/m^3-day)	BOD_5			
				Mean	Stand Dev.†	Number Samples	Percent Removal
First Winter Parallel Operation	Inf	-	-	136	31	11	-
	Eff	17.8	7.8	35	15	11	74
First Summer Parallel Operation	Inf	-	-	137	124-155	5	-
	Eff	20.9	6.6	30	13-49	5	78
First Summer Series Operation	Inf	-	-	137	77-175	8	-
	Eff	19.5	7.0	22	11-30	8	84
Second and Third Winter Parallel Operation	Inf	-	-	158	48	30	-
	Eff	22.8	6.9	52	13	30	67
Second Summer Series Operation	Inf	-	-	139	109-223	6	-
	Eff	22.1	6.3	79	10-163	6	43
Second Summer Parallel Operation	Inf	-	-	133	14	10	-
	Eff	31.0	4.3	55	15	10	59
				SS			
First Winter Parallel Operation	Inf			80	15	11	-
	Eff			37	10	11	54
First Summer Parallel Operation	Inf			81	71-97	5	-
	Eff			31	19-44	5	62
First Summer Series Operation	Inf			84	72-61	9	-
	Eff			21	10-61	9	75
Second and Third Winter Parallel Operation	Inf			74	28	30	-
	Eff			41	8	30	45
Second Summer Series Operation	Inf			64	57-79	6	-
	Eff			36	19-52	6	41
Second Summer Parallel Operation	Inf			73	15	10	-
	Eff			43	8	10	43

* No COD's reported.

† The range is shown where the number of samples collected is less than ten.

treatment efficiency. The poor second summer series operation may have been caused by septic tank sludge as evidenced by the high BOD levels compared to the SS levels. The septic tank sludge was not accounted for in the influent parameter values.

Coliforms

Performance of the chlorination contact chamber was somewhat erratic with the poorest performance occurring in June and July, 1975 (Table 13). The greatest concentration of algae may have been produced at that time, however, the lowest rate of chlorine feed also occurred during that period. In the original design of the chamber, the chlorine feed line entered the pond next to the chamber influent line. The chlorine feed was modified during the spring of 1975 to enter the waste stream at the effluent collection man hole which allows mixing in 6 m of pipe before entering the contact chamber. This modification has improved the chlorination effectiveness as evidenced by the winter parallel data.

PALMER AERATED LAGOON AND POLISHING POND

Lagoon Description

The original Palmer waste treatment system, which drained into a facultative lagoon, was replaced in the summer of 1972 with an aerated lagoon which also discharged to the facultative lagoon. The aerated lagoon and the polishing pond were of earthen dike

Table 13. EAFB Full Scale Lagoon Disinfection Summary

Period	Nominal Contact Time (Min)	Chlorine Feed (mg/l)	Chlorine Residual (mg/l)	Fecal Coliforms/100 ml*	No. of Samples
Winter Parallel					
11/19/74-02/11/75	37	--	0.7	1,994 (98)	6
11/04/75-02/24/76	42	6.6	0.6	17,260 (92)	16
Summer Series					
06/03/75-07/08/75	37	4.4	0.3	0-TNC†	8
Summer Parallel					
09/05/75-10/07/75	53	7.6	0.4	111 (29)	10

* Values in parantheses = geometric mean.

† Included 3 values of 0 and 4 TNC (too numerous to count).

construction with a side slope ratio of 3:1 and sealed with bentonite. Common dimensions of the aerated lagoon were 30 m X 220 m. The aerated lagoon volume was 24,600 m^3 at an operating depth of 2.7 m. Aeration was provided by perforated tubing diffusers. The polishing pond area and volume were 17,846 m^2 and 27,250 m^3 respectively at an operating depth of 1.5 m.

Operation Problems

The lagoon began operation in October, 1972 and has suffered from relatively few operating problems, apparently due to the relatively light loading on the lagoon, the overall design and the excellent maintenance provided. Sludge which had accumulated in the polishing pond before installation of the aerated lagoon occasionally would rise to the surface after operation began. The rising sludge did not create a nuisance and has not been observed since the first year of operation.

Destruction of the aeration pattern by bottom sludge settling near the influent line occurred in the aerated lagoon and the system was drained for repair during the summer, 1975. About 0.6 m of sludge was found around the inlet pipe. The depth tapered to a few centimeters at a distance of 6 m from the inlet pipe. After the sludge had dried, a backhoe was used for removal and the tubing replaced in that area. An additional aeration device was placed near the influent line for the purpose of resuspending the bottom sludge so that recurrence of the problem may be prevented. The effectiveness of the new device has not been determined.

BOD and SS Removals

Operating results are presented in Table 14 and Figure 21. The data was supplied by the City of Palmer. Samples were collected 3 times per week by the city operators and pH, DO and temperatures recorded and SS determined. BOD analyses were made once per week. BOD, DO and SS analyses were performed with Hach Kits.

Polishing pond effluent dissolved oxygen levels have been included in the graph as an indication of the polishing pond effects. As may be expected, the DO levels were high in the summer due to algae action and low in the winter. The winter DO measurements consistently leveled off at 2 mg/liter. DO levels from the aerated lagoon average about 8 mg/liter in the winter which apparently maintain the 2 mg/liter level in the polishing pond effluent.

The overall system has provided consistently good treatment with little difference in winter and summer periods.

Aerated lagoon effluent data was collected from July 2 through September 12, 1973, a period during which the polishing pond was not in operation. The data indicated that the aerated lagoon by itself attained 55% BOD removal. When compared with 91% BOD

Table 14. Performance Summary of Palmer Lagoon*

Operation	Station	Det. Time	Loading/day	BOD$_5$				SS			
			g/BOD$_5$/m^3/day	Mean	Std Dev†	# Samples	% Rem	Mean	St. Dev	# Samples	% Rem
Aerated Lagoon Only 07/02/73-9/12/73	.Inf	51.6	3.5	182	125-270	8	-	128	64	32	-
	Eff			42	15-110	9	77	58	38	28	55
Winter - Aerated Lagoon plus Facultative Lagoon 01/07/74-04/01/74 12/04/74-03/28/75 12/01/75-03/31/76	Inf	106.0	1.8	192	83	43	-	184	61	141	-
	Eff			16	14	41	92	17	4	141	91
Summer - Aerated Lagoon plus Facultative Lagoon 05/17/74-07/17/74 08/09/74-09/09/74	Inf	102.7	2.0	209	60	13	-	181	59	41	-
	Eff			6	4	13	97	18	11	41	90
Overall - Aerated Lagoon plus Facultative Lagoon 05/01/74-04/30/75	Inf	109.6	1.7	188	74	47	-	185	56	156	-
	Eff			11	12	45	94	17	7	147	91

* No COD's reported.

† Range of values given for No of samples less than 10.

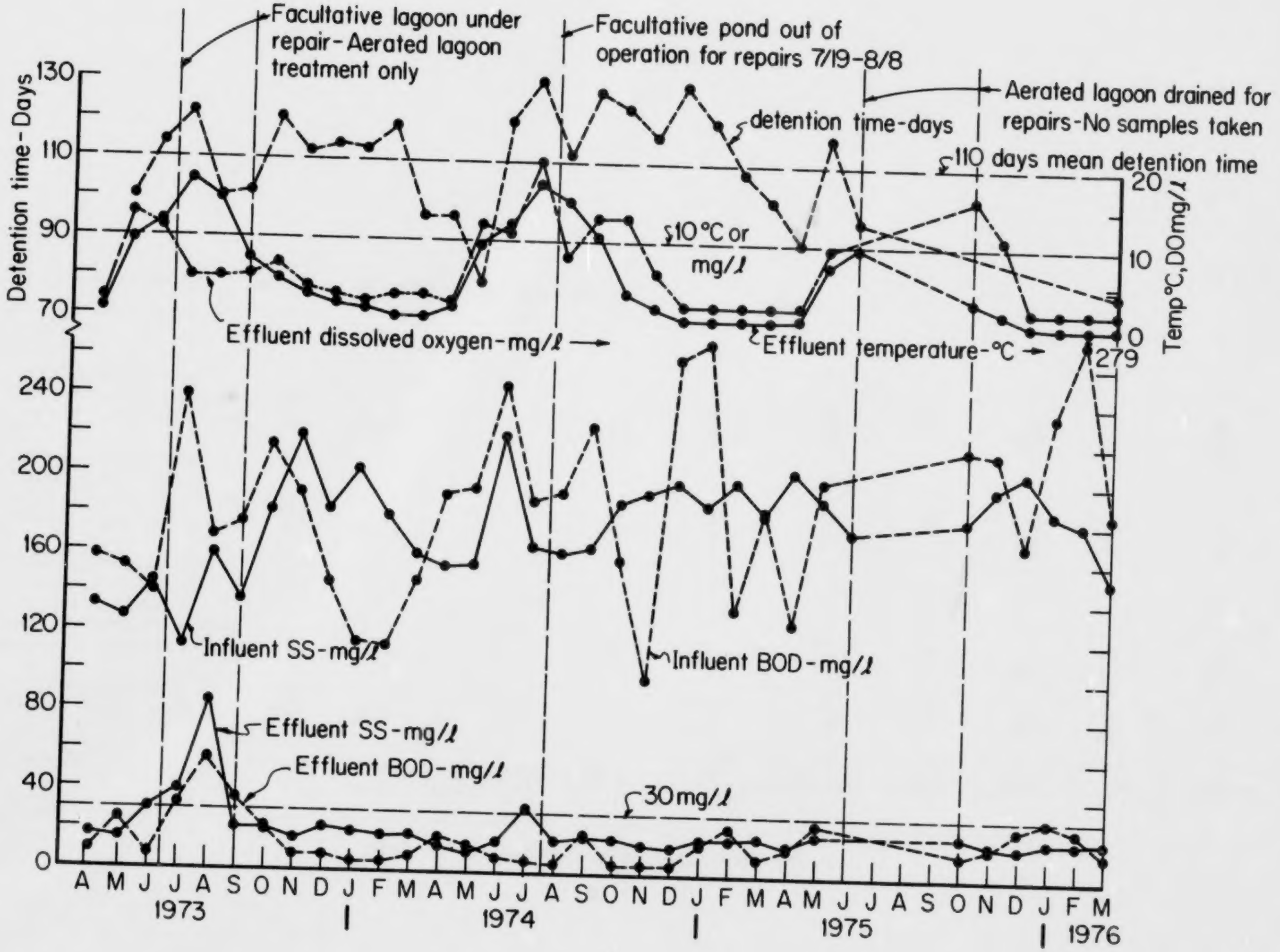

Figure 21. Palmer lagoon operating results.

removal for the aerated lagoon-polishing pond combination, one can infer that a significant amount of treatment is taking place in the polishing pond.

The period from May 1, 1974 to April 30, 1975 was selected as a typical full year's operation and plotted on probability paper (Figure 22). The effluent BOD and SS exceeded 30 mg/l 10% and 4% of the time respectively. The effluent SS exceeded 70 mg/l less than 1% of the time.

A major portion of treatment in the polishing pond is similar to the treatment which occurs in the aerated cells, i.e., settleable solids deposit under quiescent conditions and the settled sludge undergoes anaerobic decomposition. Assimilation and oxidation of organic matter and oxidation of biological solids occur at a very reduced rate because concentrations have been reduced by treatment in the aerated cells.

During summer months, algae removal occurs through sedimentation and subsequent anaerobic decomposition and through consumption by higher organisms. These various phases of treatment are discussed in Section 7.

STUDIES BY OTHERS

To arrive at a more comprehensive picture of cold climate aerated lagoon performance BOD and SS data on lagoons outside Alaska were

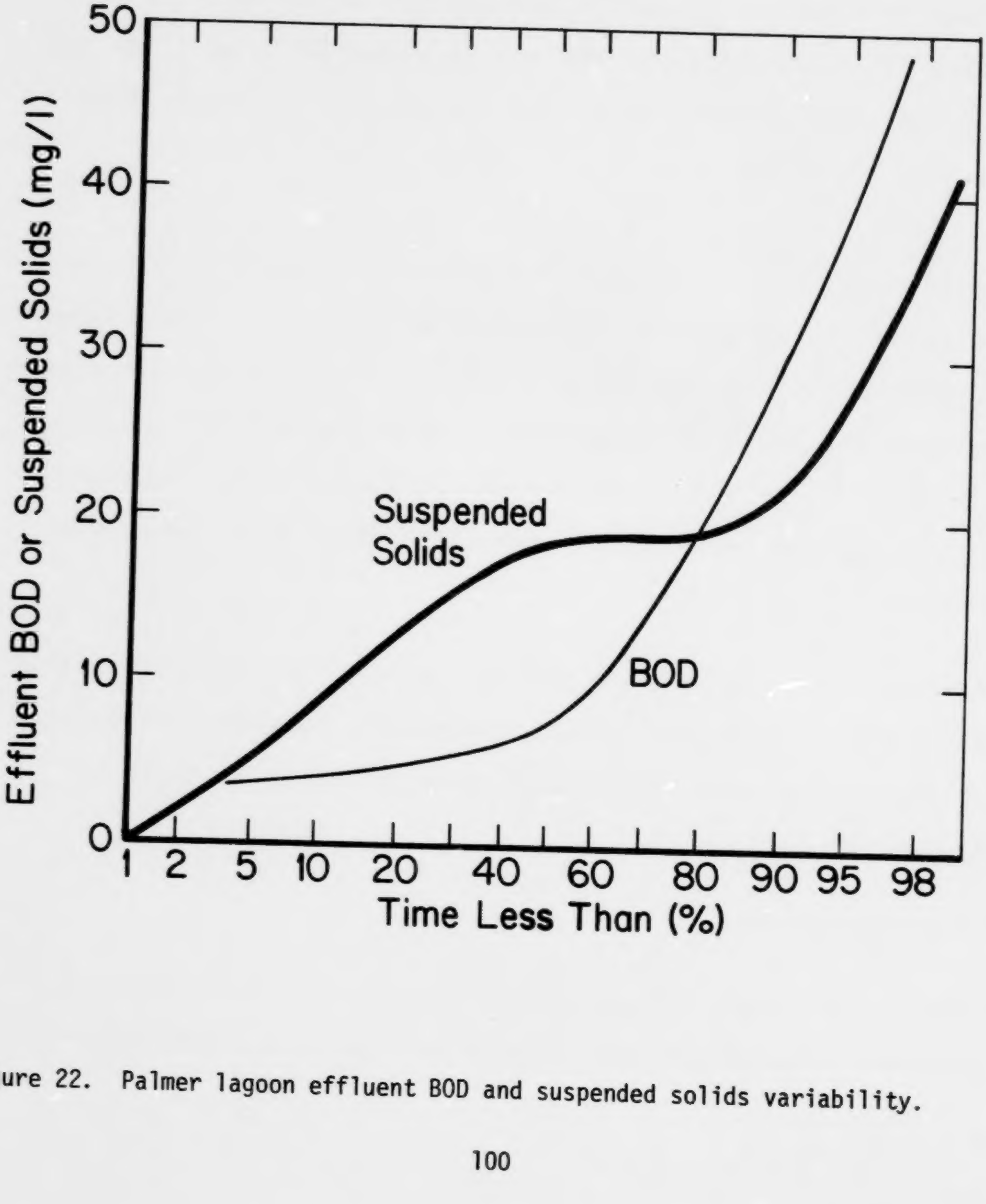

Figure 22. Palmer lagoon effluent BOD and suspended solids variability.

incorporated in our analysis. These lagoons are in Eagan Township, Winsted and Redwood Falls, Minnesota (Breinhurst, 1970); three lagoons near Winnepeg, Manitoba (Penman et al., 1970) and a lagoon at Harvey, N. Dakota (Vennes, 1970).

The BOD and SS removals obtained with these lagoons is summarized in Tables 15 through 17. Fecal and total coliform results for the Harvey, N. Dakota lagoon are also presented in Table 18.

Table 15. Performance Summary of Minnesota Lagoons*

Lagoon	Station	Detention Time (Days)		Loading (g BOD_5/m^3-day)		BOD_5				
							Stand	Number	Percent Removal	
		Per Cell	Accum.	Per Cell	Accum.	Mean	Dev.	Samples	Per Cell	Accum
Eagan, Minn										
2nd & 3rd years	Inf	-	-	-	-	1225	880-1750	10	-	-
	Cell -1	7.0	7.0	175.0	175.0	225	60	12	83	83
	-2	8.4	15.4	26.8	79.6	113	73	21	50	91
3rd Winter	Inf	-	-	-	-	1107	960-1255	3	-	-
	Cell -1	9.2	9.2	120.3	120.3	257	222-290	3	77	77
	-2	9.9	19.1	26.0	58.0	159	44-218	5	38	86
2nd & 3rd Summer	Inf	-	-	-	-	1324	880-1750	6	-	-
	Cell -1	5.5	5.5	240.7	240.7	178	118-230	6	87	87
	-2	6.8	12.2	26.2	108.5	116	78	10	35	91
						SS				
Eagan, Minn										
2nd & 3rd years	Inf					764	264-2110	10	-	-
	Cell -1					823	302	11	17	17
	-2					310‡	180	21	62	69
3rd Winter	Inf					372	273-446	3	-	-
	Cell -1					413	300-545	3	0	0
	-2					148	33-220	5	64	60
2nd & 3rd summer	Inf					1069	330-1880	5	-	-
	Cell -1					1009	790-1220	5	6	6
	-2					538	529	10	47	50

(Continued)

Table 15. Continued

Lagoon	Station	Detention Time (Days)		Loading (g BOD_5/m^3-day)		BOD_5				
		Per Cell	Accum.	Per Cell	Accum.	Mean	Stand Dev.	Number Samples	Percent Removal Per Cell	Percent Removal Accum
Redwood, Minn 2nd Year	Inf	-	-	-	-	169	38	12	-	-
	Cell -1	14.1	14.1	12.0	12.0	39‡	11	11	77	77
	-2	31.6	45.7	1.2	3.7	32	17	12	18	81
	-3	42.0	87.7	0.8	1.9	15	7	20	54	91
2nd Winter	Inf	-	-	-	-	167	170-215	3	-	-
	Cell -1	18.0	18.0	9.3	9.3	51	50-52	2	70	70
	-2	37.0	55.0	1.4	3.0	15	10-23	3	71	91
	-3	44.0	99.0	0.3	1.7	9	8-11	5	40	95
2nd & 3rd Summer	Inf	-	-	-	-	156	100-225	6	-	-
	Cell -1	12.1	12.1	12.9	12.9	36‡	26-165	6	77	77
	-2	28.1	40.2	1.3	3.9	34‡	13-68	6	8	79
	-3	33.8	74.0	1.0	2.1	19	6-33	9	44	88
Winsted, Minn 2nd & 3rd Year	Inf	-	-	-	-	930‡	450	12	-	-
	Cell -3	-	74.0	-	12.6	62	42	19	-	93
3rd Winter	Inf	-	-	-	-	857	540-1290	3	-	-
	Cell -3	-	68.0	-	12.6	75	30-112	5	-	91
2nd & 3rd Summer	Inf	-	-	-	-	1060‡	290-1990	6	-	-
	Cell -3	-	74.0	-	14.3	57	7-125	9	-	95

(Continued)

Table 15. Continued.

Lagoon	Station	SS				
		Mean	Stand Dev.	Number Samples	Percent Removal	
					Per Cell	Accum
Redwood, Minn 2nd Year	Inf	202	41	12	-	-
	Cell -1	95	50	10	53	53
	-2	60	32	12	37	70
	-3	42	27	19	30	79
2nd Winter	Inf	258	215-334	3	-	-
	Cell -1	58	48-68	2	78	78
	-2	21	16-25	3	63	92
	-3	20	14-38	5	7	92
2nd & 3rd Summer	Inf	187	146-232	6	-	-
	Cell -1	134	86-172	5	28	28
	-2	85	59-110	6	36	54
	-3	64	25-107	8	26	66
Winsted, Minn 2nd & 3rd Years	Inf	479	197	12	-	-
	Cell -3	77	55	19	-	84
3rd Winter	Inf	318	243-358	3	-	-
	Cell -3	106	46-170	5	-	67
2nd & 3rd Summer	Inf	619	340-835	6	-	-
	Cell -3	64	7-150	9	-	90

* No COD's reported.

† Range of values reported for number of samples less than 10.

‡ Adjusted from probability plot.

Table 16. Performance summary of Winnepeg lagoons.*

Operation	Station	Detention Time	Loading g BOD/m^3-day	BOD$_5$		SS	
				Mean	% Removal	Mean	% Removal
First & Second Years Overall (21 months)	Influent	-	-	175	-	188	-
	Effluent						
	Air Aqua	30	5.8	37	79	34	82
	Surface Aerator	20	8.8	38	78	39	79
	Air Gun Aerator	20	8.8	34	81	34	82
First and Second Winter	Influent	-	-	206	-	199	-
	Effluent						
	Air Aqua	30	6.9	41	80	42	79
	Surface Aerator	20	10.3	47	77	56	72
	Air Gun	20	10.3	39	81	45	77
First Year Summer	Influent	-	-	133	-	157	-
	Effluent						
	Air Aqua	30	4.4	21	85	32	80
	Surface Aerator	20	6.7	19	86	31	80
	Air Gun	20	6.7	15	89	32	80
Series Operation Jan, Feb, Mar, 1972	Influent	-	-	223	-	263	-
	Effluent						
	No 1 Secondary	-	-	124	-	41	-
	Air Gun	6.2	20.0	82	34	56	(-37)
	Surface Aerator	12.4	10.0	57	54	91	(-122)
	Air Aqua 1	17.1	7.3	44	65	51	(-24)
	Air Aqua 2	21.8	5.7	36	71	32	22

* No COD's reported.

Table 17. Performance summary of Harvey, N. Dak. Aerated Lagoon.*

Period	Station	Detention Time (Days)		Loading (g BOD_5/m^3-day)		BOD_5				
		Per Cell	Accum.	Per Cell	Accum.	Mean	Stand Dev.	Number Samples	Percent Removal Per Cell	Percent Removal Accum
1st through 4th years	Inf	-	-	-	-	263	134	-	-	-
	Cell -1	20	20	13.2	13.2	126	76	-	52	52
	-2	20	40	6.3	6.6	53	45	-	58	80
Winter 1st, 2nd and 4th years Jan through Mar	Inf	-	-	-	-	312	180	-	-	-
	Cell -1	20	20	15.6	15.6	129	10	-	59	59
	-2	20	40	6.5	7.8	50	23	-	61	84
Winter 3rd year Jan through Mar	Inf	-	-	-	-	665	950	-	-	-
	Cell -1	20	20	33.3	33.3	226	65	-	66	66
	-2	20	40	11.3	16.6	160	19	-	29	76
Summer 1st through 4th years June through Sept	Inf	-	-	-	-	280	117	-	-	-
	Cell -1	20	20	14.0	14.0	93	28	-	67	67
	-2	20	40	4.7	7.0	28	23	-	70	90
						VSS				
1st through 4th years	Inf					166	118	-	-	-
	Cell -1					118	74	-	29	29
	Cell -2					67	39	-	43	60
Winter 1st, 2nd and 4th years Jan through Mar	Inf					221‡	152-316	7	-	-
	Cell -1					111‡	58-172	8	50	50
	-2					72‡	32-104	8	35	67
Winter 3rd year Jan through Mar	Inf					190‡	100-322	6	-	-
	Cell -1					187‡	100-524	6	2	2
	-2					124‡	90-160	6	34	35
Summer 1st through 4th years June through Sept	Inf					185‡	114-312	7	-	-
	Cell -1					117‡	40	13	37	37
	-2					71‡	37	13	39	61

* No COD's reported.

† The range is shown where the number of samples is less than 10.

‡ Calculated from the data reported.

Table 18. Harvey, N. Dak Aerated Lagoon Fecal and Total Coliform Results

	Feed	Cell 1	Cell 2
		Fecal Coliforms	
Jan-Mar (66,67,69)	1.1×10^6	6.0×10^5	7.9×10^4
% Removal		45	93
Jan-Mar (68)	7.4×10^6	2.5×10^6	1.0×10^6
% Removal		66	86
June - Sept (All)	1.3×10^7	1.3×10^6	1.0×10^4
% Removal		90	99.92
		Total Coliforms	
Jan-Mar (66,67,69)	6.9×10^6	1.8×10^6	4.8×10^5
% Removal		74	93
Jan-Mar (68)	6.8×10^7	7.3×10^6	5.4×10^6
% Removal		89	92
June - Sept (All)	6.9×10^7	4.2×10^6	7.0×10^4
% Removal		94	99.90

SHORT-CIRCUITING

Short-circuiting is one of the most important problems with lagoons, with wind playing a major role (Barsom, 1973). Dye studies were conducted on the Ft. Greely lagoon in order to gain an idea of the degree of short-circuiting taking place for that particular lagoon design.

The dye studies were conducted over 24 hour periods. Observations were recorded in terms of relative concentrations because dye adsorption and decay could be expected to invalidate absolute results.

The first test was made on the coarse bubble diffuser side but had to be abandoned because of very high winds which developed. Some information was gathered, however. One hundred fifty ml of Rhodamine B dye was added at the splitter manhole. Evidence of dye was seen at the first two inlets of the influent header after 2 minutes. The dye then began to drift toward the center baffle near the dike with some mixing with the aerator cluster. The dye continued to mix with the aeration cluster but also drifted over the center baffle. Visible evidence of the dye was seen over halfway into the 2nd cell along the dike. Short circuiting was obviously taking place with the high winds making a major contribution to the problem.

Additional dye studies were conducted at a later date under calmer wind conditions. The patterns of visible dye movement observed are shown in Figure 23. Again the wind, although very light, had a major effect on the apparent short-circuiting which was taking place. Times required for the dye to reach the effluent are shown in Figures 24 and 25. The readings were taken with a Turner fluorometer and are plotted as relative concentrations. In this case 750 ml of Rhodamine B dye were added to both the coarse bubble and fine bubble diffuser sides of the lagoon. The peak concentrations of dye reached the far end of the coarse bubble side in about 3.5 hours and the effluent at 4 hours. The relative concentration at the effluent dropped from 28 at 4 hours to about 7 at 7.5 hours and then began a gradual climb and leveled off around 22 at 21 hours. The effluent peak at 4 hours for the coarse bubble lagoon was obviously due to short circuiting. The gradual increase from the low at 7.5 hours to the leveling off at 20 hours and greater was due to dye which entered the aeration pattern. This type of curve is more likely to occur under complete mix conditions without short circuiting. On this basis the dye concentration peak for the far end occurred at about 3 hours due to the high level of mixing in the first cell. The peak for the effluent did not occur until after 20 hours because of the low mixing level occurring in the second cell.

A similar action occurred in the fine bubble side of the lagoon. The dye concentration peaked at 31 at 4.5 hours on the far end

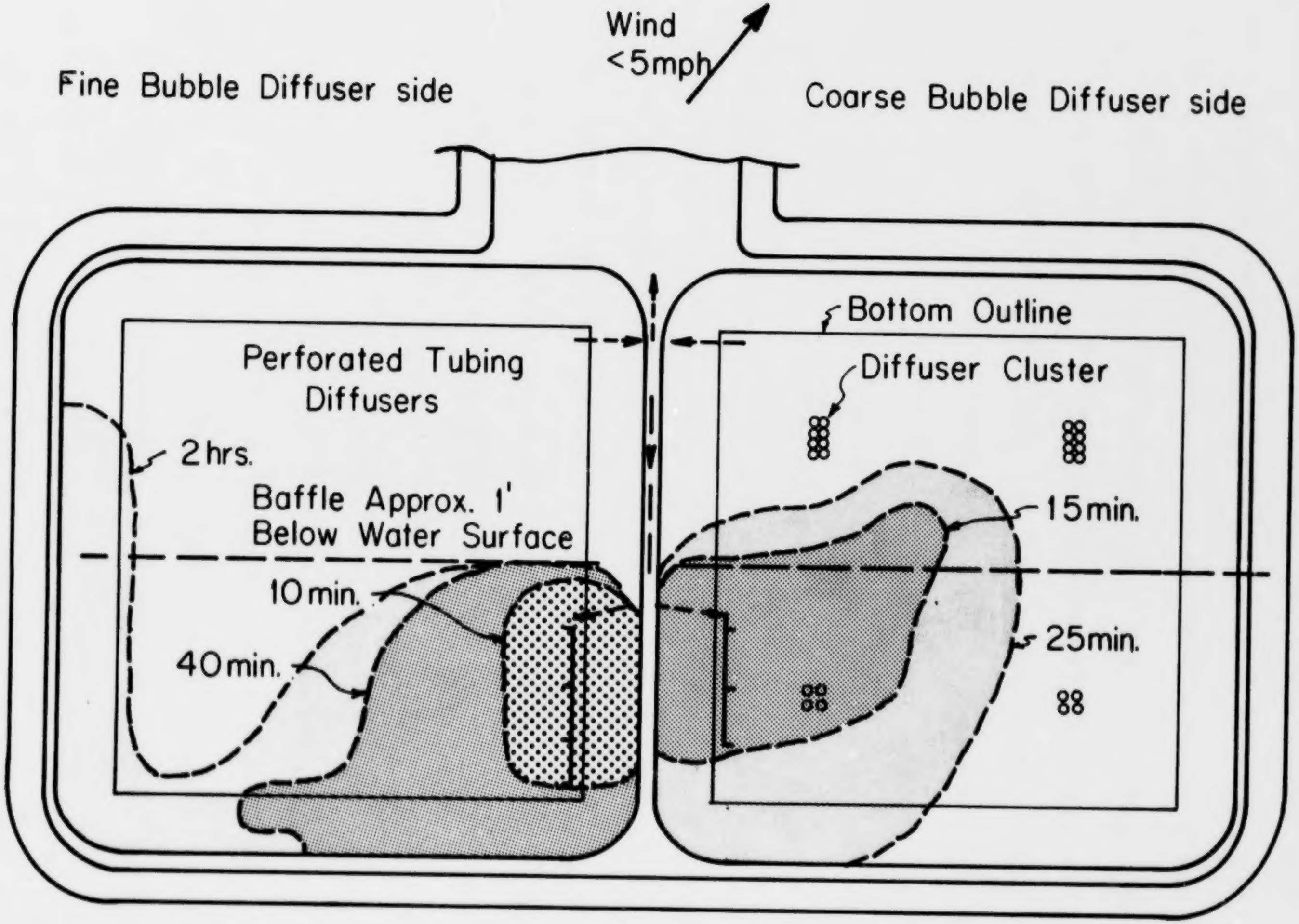
Wind
<5mph
Fine Bubble Diffuser side
Coarse Bubble Diffuser side
Bottom Outline
Diffuser Cluster
Perforated Tubing
Diffusers
2 hrs.
Baffle Approx. 1'
Below Water Surface
10 min.
40 min.
15 min.
25 min.

Figure 23. Visual observation of dye injection in the Ft. Greely lagoon.

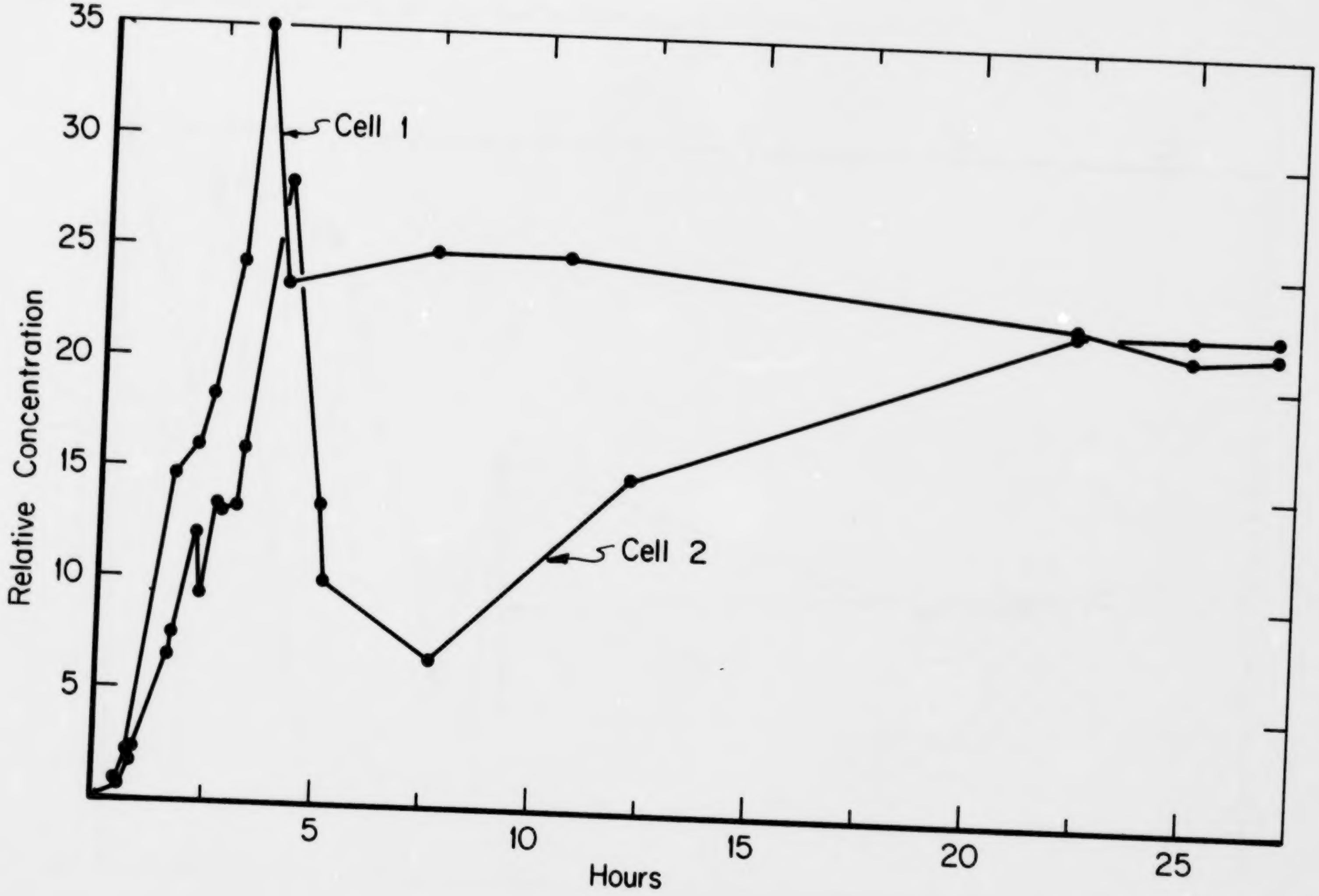

Figure 24. Dye injection results, Ft. Greely coarse bubble aerated lagoon.

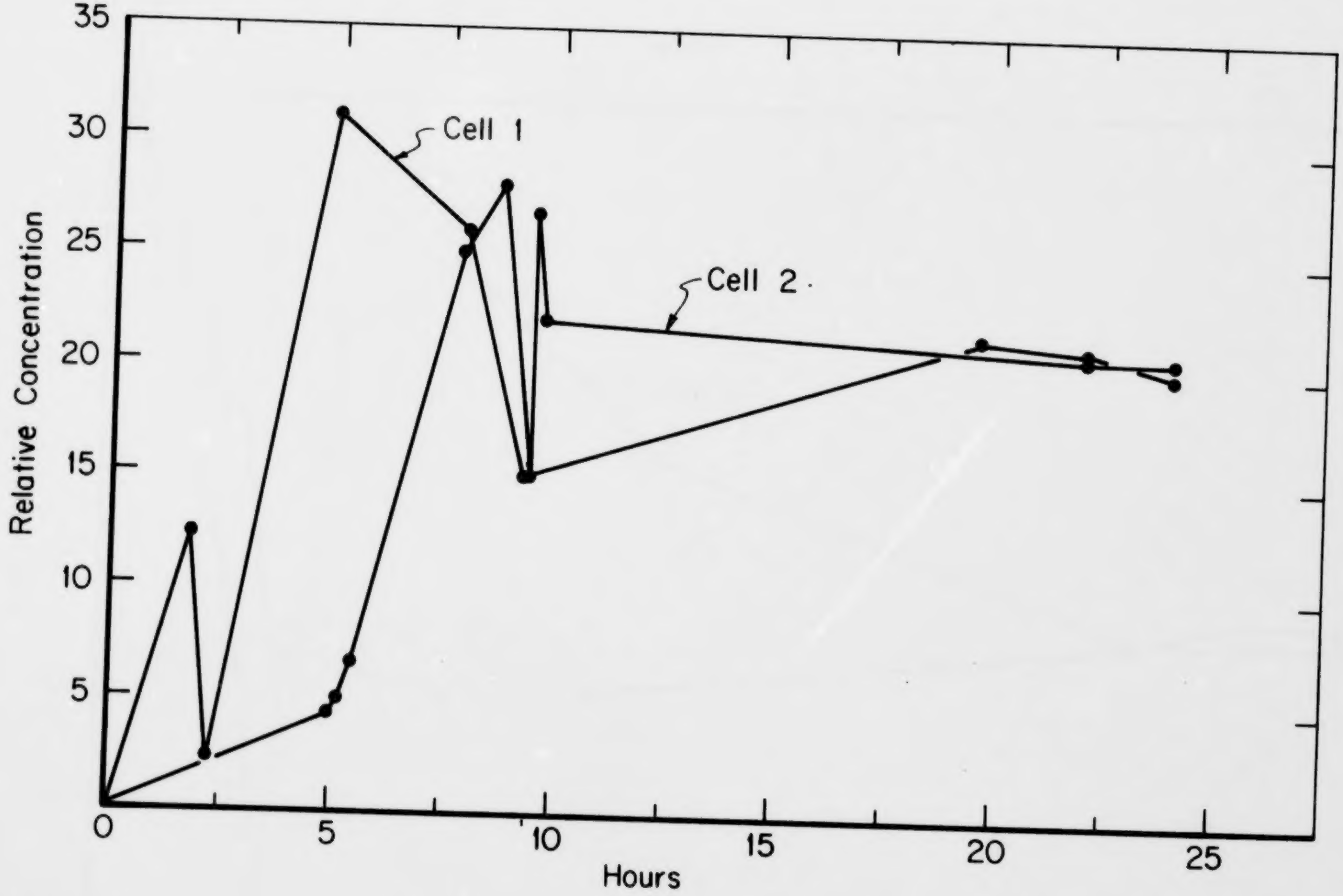

Figure 25. Dye injection results, Ft. Greely fine bubble aerated lagoon.

of the lagoon. Heavy concentrations were visible near the dike at the far end at less than two hours and a sample taken at this point read off the scale on the fluorometer. Samples at the far end of both lagoons were normally taken off the end of the dock. The curves for the fine bubble side are somewhat more erratic due to the channeling of the dye around the aeration pattern in the first cell (Figure 23). It is not known if channeling occurred in the second cell since the dye became less visible at this point. The effluent peak occurred around 8.5 hours, which was about 4 hours later than for the coarse bubble side, and dropped to around 15 before climbing back to about 21 at 20 hours.

FT. GREELY OXYGEN TRANSFER STUDIES

METHODS AND PROCEDURES

In order to compare the performance of the coarse and fine bubble aerators, oxygen transfer studies were conducted at the Ft. Greely lagoon. DO uptake values were determined through the use of a bottom sludge respirometer constructed at the AERS laboratory and with light and dark BOD bottle uptake measurements.

Three docks were placed on each half of the lagoon as shown in Figure 6 to facilitate sampling. DO levels in the lagoon were determined with a YSI meter (Model 54) and probe (Model 5418). DO's were measured at various points throughout the lagoon at the beginning of the sampling season and found to be reasonably uniform or within approximately 1 mg/l throughout each half of the lagoon. Thereafter, DO's were determined at mid-depth from the three docks on each half of the lagoon and the DO levels reported are an average of these.

DO uptakes were determined by bringing samples into a laboratory building and shaking the samples for aeration. The samples were then placed in BOD bottles in a water bath at the same temperature as the lagoon and the DO's read with the YSI meter (Model 54) and YSI BOD probe (Model 5420). This procedure was accomplished within a few minutes. The bottles were agitated and the DO levels read periodically during the uptake period. Uptake rates were determined from curves obtained by plotting DO levels versus time.

Uptake rates obtained during periods of algae growth were determined by the use of light and dark BOD bottles as described by Camp (1963). Samples were collected at two depths in the lagoon, 1 foot and 7 foot levels, and placed in four BOD bottles, two of which were painted black to prevent light penetration. Initial DO levels were determined in each bottle and these were hung in the lagoon at the respective sample depths. The bottles were then removed periodically in alternate pairs and the DO levels determined.

The bottom sludge respirometer consisted of an 8 inch diameter plastic tube open at the bottom and with a flat cover on the top. Mounted on the top were a YSI model DO probe and a small submersible pump supplied by The Little Giant Pump Co., Oklahoma City, Oklahoma. A large surface area flange was placed around the bottom to prevent the respirometer from sinking into the sludge. The bottom of the respirometer was extended 2 inches with a piece of sheet metal to ensure a good seal at the sludge face.

The submersible pump and probe were mounted so the pump discharged over the DO probe eliminating any stagnation. The discharge was restricted so that the flow was very gentle and a minimum of stirring occurred in the respirometer.

When using the respirometer, a plug was removed from the top and the respiormeter submerged. All of the trapped air was allowed to escape and the plug replaced. The unit was then lowered into place and the submersible pump started. Periodic DO readings were taken over periods which ranged from 1 to 4 hours.

The true uptake rate of the bottom sludge was determined by subtracting the lagoon liquid uptake rate determined in the BOD bottles from the rate established in the respirometer.

Values of 0.85 and 0.90 were used for α and β respectively, for all calculations. These values were obtained through laboratory tests conducted in a 10-liter cylindrical shaped container. Lagoon effluent was brought to the laboratory, held overnight, and two runs made with effluent and two runs with tap water on the same day, in accordance with the procedure outlined by Eckenfelder and Ford (1970). Gentle aeration was provided with a glass tube of 3 mm diameter. A value for β was obtained by aerating the container contents for an extended period and comparing the saturation value obtained with the standard value for the corresponding temperature and pressure. A θ value of 1.02 was used for temperature correction of the K_La values obtained in these studies. C_s was calculated for mid-depth in accordance with methods discussed earlier.

RESULTS

Table 19 presents the oxygen transfer data collected and is grouped by type of aerator. Also shown is one data point for the Northway lagoon which at that time had Air Gun aerators. The last data point is taken from the literature and represents an evaluation of an Air Gun installation at Brampton, Ontario (Thon, 1964). The data include the effect of surface aeration.

Horsepower requirements were calculated based on the following formula (Fair et al., 1971):

$$hp = 0.227\ Q\ \left((P_2/P_1)^{0.283} - 1\right)$$

Q = Air flow in SCFM (14.7 psia and 70°F)

P_2 = Discharge pressure of blower (psia)

P_1 = Atmospheric pressure (psia)

1 hp = 0.746 kW

An overall efficiency loss of 30 percent was assumed for the blower and motor for all calculations. Actual blower discharge pressures were used for the Ft. Greely fine bubble and Northway Air Gun calculations, while 125 percent of the submergence depth, or 0.35 kg/cm^2 was used for the coarse bubble diffusers. This assumes a pressure loss of 0.02 kg/cm^2 through the main header since the pressure measured at the point of the coarse bubble air

Table 19. Oxygen Transfer Summary

Aerator	Date	Liquid Temp °C	Ice Cover %	D.O. Level mg/l	D.O. Uptake mg/l/hr	Air Supply l/sec - 1000 m³	O_2 Transfer Efficiency %	K_La (hr^{-1})		kg O_2/KW-hr
								Calcu-lated	Adjusted to 20°C	
Ft. Greely Coarse Bubble	Feb 18	<0.5	90	6.9	0.34	9.0	3.8	0.064	0.094	0.86
	Apr 6	<0.5	40	9.1	0.23	12.7	1.9	0.054	0.079	0.44
	Apr 28	5.2	0	5.2	0.30	11.7	2.7	0.049	0.066	0.64
	May 18	10.5	0	7.0	0.46	13.5	3.7	0.142	0.170	0.92
	Nov 30	1.0	30	3.8	0.42	12.2	3.5	0.049	0.071	0.82
	Dec 22	1.0	70	0.7	0.34	8.7	4.0	0.030	0.044	0.96
Ft. Greely Fine Bubble	Feb 18	<0.5	100	9.1	0.21	8.7	2.5	0.047	0.069	0.33
	Apr 6	<0.5	50	3.2	0.17	4.5	4.1	0.019	0.028	0.65
	Apr 28	5.2	0	1.0	0.18	4.3	4.4	0.019	0.025	0.60
Northway Air Gun	May 23	8.0	0	5.0	0.37	21.5	1.7	0.070	0.088	0.43
Brampton Air Gun (Thon, 1964)		14.8	0	3.6	0.43	17.2	2.6	0.064	0.073	0.44

lines tied into the main header was approximately 0.33 kg/cm^2. The Brampton Air Gun data point was calculated by the author of that paper using the submergence depth of the aerators, about a 20 percent inherent efficiency loss for compression and a 35 percent efficiency loss for the aeration system (Thon, 1964).

Mixing over the center baffle was too great to permit separate evaluation of the two types of coarse bubble diffusers at Ft. Greely. As a result, the diffuser performances have been lumped together for evaluation. This should not detract substantially from the results as any difference between the two coarse bubble aerators will be small compared to that between the coarse bubble and fine bubble aerators.

The progressive drop in DO levels for the fine bubble diffuser shown in Table 19 is a result of the clogging mentioned previously. Data for the fine bubble aerator were not obtained on May 18 because the lagoon had gone anaerobic at that time. Oxygen transfer data for November and December were not obtained because the repunching of the tubing which occurred during the summer changed the fine bubble diffuser characteristics. The higher DO uptake values reported for the coarse bubble diffusers were a result of higher influent flows to that side.

Figure 26 presents a plot of the K_La value at 20°C times the aeration basin volume per diffuser ($K_La \times V$) versus the air flow rate per diffuser (1.0 SCFM = 0.47 liters/sec). The coarse

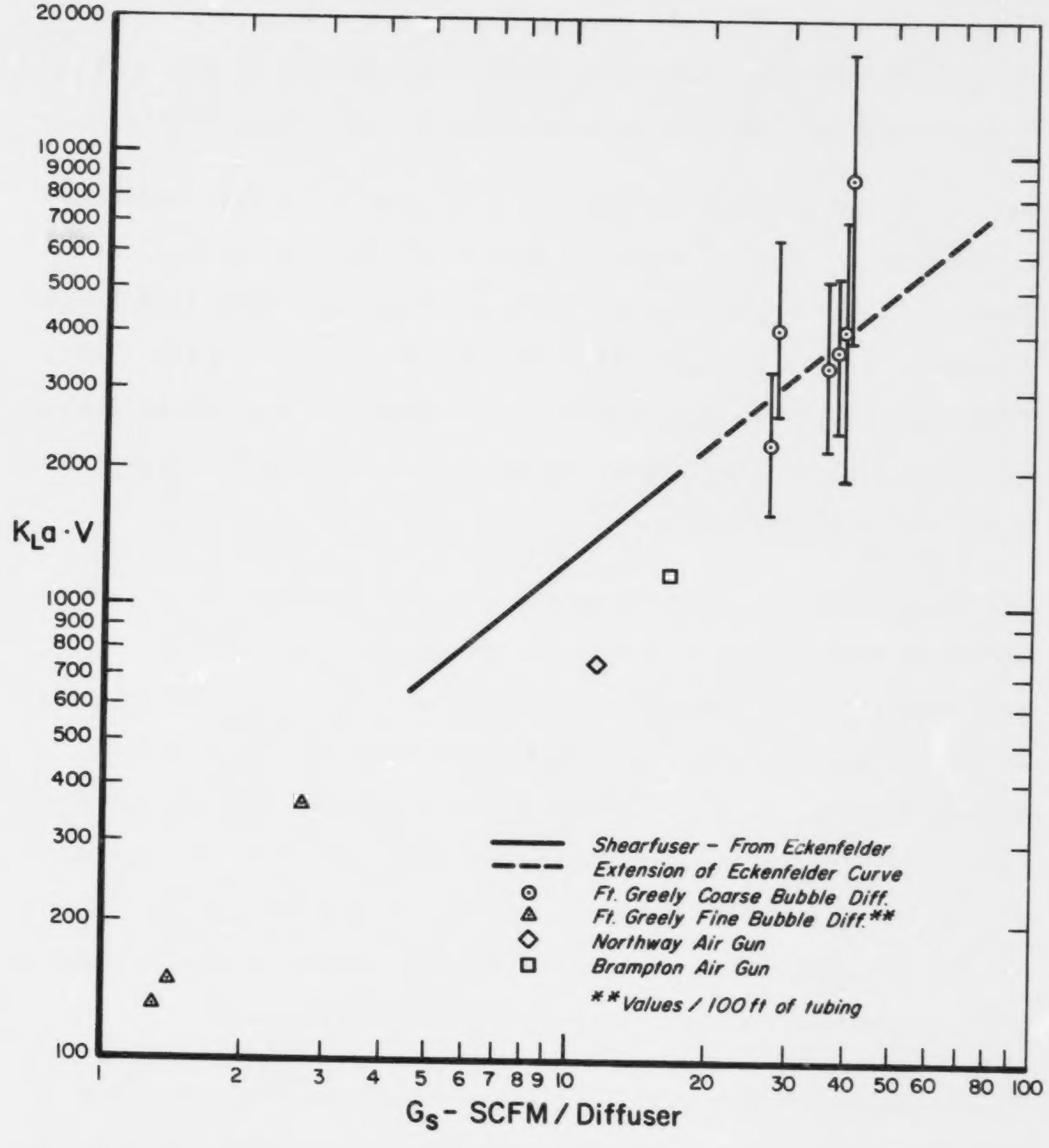

Figure 26. Air flow rate vs. $K_L a \cdot V$ for aerated lagoons.

bubble diffusers were evaluated as Shearfusers. This was done because, situated in the first cell where the oxygen demand was greatest, the Shearfuser clusters received the major portion of the total air flow (approximately 80 percent). Each Aer-O-Flo diffuser cluster was considered as on Shearfuser diffuser (based on air flow) which made a total of 10 Shearfusers for calculation purposes.

The solid line shown was obtained from the literature and relates the K_La value for a certain diffuser and tank configuration to the tank volume per diffuser (Eckenfelder and O'Connor, 1961). The curve is based on data obtained in a tank 7.3 m long by 1.2 m wide by 4.6 m deep, using the Shearfuser diffusers. Other curves for similar coarse bubble diffusers were shown in the reference but are not presented here.

Because of the variability of the Shearfuser data obtained at Ft. Greely, maximum and minimum values of K_La based on possible errors in procedures and equipment were calculated and a range of K_La values were plotted as shown. The accuracies used in the calculations were as follows:

C = ±0.5 mg/l - Standard Methods indicates an accuracy of ±0.1; however, ±0.5 was used because of the slow instrument response to the cold conditions during the studies.

r = ±15 percent - Sawyer and McCarty (1967) indicates the BOD test accuracy is considered to be 5 percent. The 15 percent value was used to account for sampling error.

β = ±0.05

α = ±0.10

The uppermost point shown represents the data for May 18 which is probably the most questionable because of the need to account for algal DO production and bottom sludge demand. The algal DO production and bottom sludge demand values were varied by +50 percent and -50 percent respectively for the error calculations.

It should be noted that the somewhat lower efficiencies exhibited by the Air Gun diffusers on Figure 26 may not be truly representative. The Northway lagoon had a liquid depth of 2.3 m which was less than would normally be provided in a lagoon designed for Air Gun aerators. Also, bottom sludge demand or algae DO production was apparently not accounted for in the Brampton study and may have been significant factors at the liquid temperature reported.

OXYGEN BUDGET

The oxygen uptake rates obtained for the Ft. Greely coarse bubble lagoon are presented to show the relationship of oxygen demand at various times of the year to the average BOD loading on the lagoon (Table 20). As may be expected the oxygen demand increased a great deal during the summer months with a good portion of the increase compensated for by algal production. It appears from the data presented that a ratio of 1.5 g O_2/g BOD_5 removed can be used for sizing aeration equipment for cold climate aerated lagoons.

Table 20. Ft. Greely Coarse Bubble Lagoon Oxygen Budget

Date	Mixed Liqour Uptake kg O_2/day	Sludge Uptake* kg O_2/day	Algae Production kg O_2/day	Aeration Requirements kg O_2/day	Ratio† BOD_5 Removed	BOD_5 Applied
02/18/72	119	-	-	119	1.5	1.1
04/06/72	83	-	-	83	1.0	0.8
04/28/72	107	-	-	107	1.3	1.0
05/18/72	213	9	59	163	2.0	1.5
06/15/72‡	446	39	155	330	4.0	3.[illegible]
11/30/72	148	-	-	148	1.8	1.4
12/22/72	120	-	-	120	1.5	1.1

* Sludge uptake rates found during the winter were less than 2 kg/day and considered negligible.

† Ratio = (kg O_2/day aeration requirement)/(Average BOD_5 applied or removed/day). The average BOD_5 applied or removed per day was 106 kg and 82 kg respectively.

‡ The data for 6/15/72 is considered unreliable because of the very high oxygen transfer rates found for the aerators. The sludge uptake rate for that date does appear reasonable.

DISCUSSION

BOD AND SS REMOVAL

Year-round BOD percentage removals were plotted in Figure 27 and curves representing plug flow and complete mix conditions were applied to the data by least squares methods. The complete mix curve having the form

$$E = (A+Kt/1+Kt)\ 100$$

where E = Percent BOD removed

A = Initial fraction of BOD removed

K = Reaction rate coefficient (1/day)

appears to most nearly represent the data. 'A' is the fraction of BOD removed within the first few hours or days through sedimentation and bio-oxidation. The equation was obtained by performing a material balance on the lagoon process (Eckenfelder, 1970) and adding a term for sedimentation. The values obtained:

$$A=0.56 \text{ and } K=0.058$$

are very similar to values reported by Reid (1970) of 0.55 for the initial removal and 0.063 for the reaction coefficient using a similar approach.

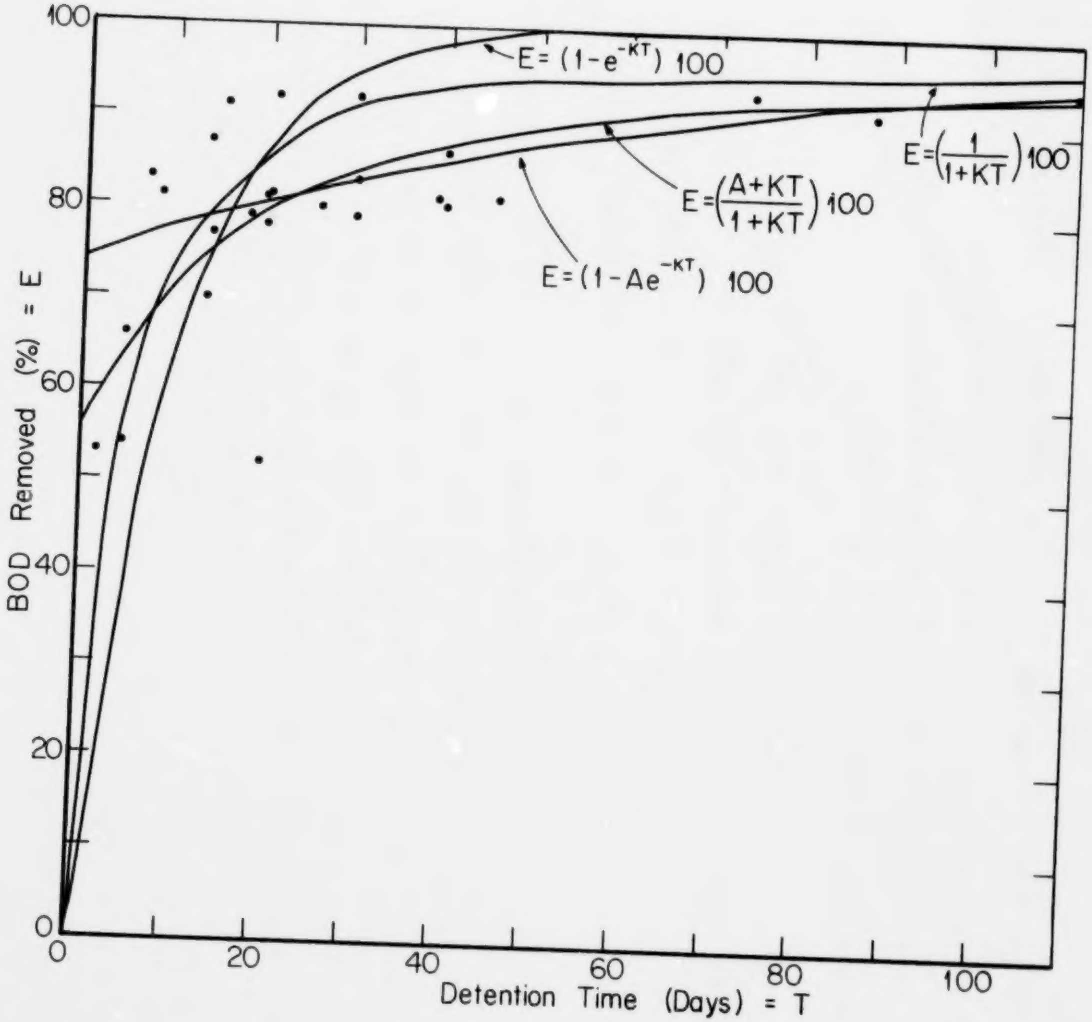

Figure 27. Year-round percent BOD removals vs. detention times.

The same equation was applied to the year-round suspended solids data and values of 0.30 and 0.058 were obtained for A and K respectively (Figure 28).

These equations were also applied to the winter and summer data (Figures 29 and 30). 'A' values were assumed to be constant at 0.56 and 0.30 in order to obtain a comparison of the reaction rates as follows:

	BOD Removal		SS Removal	
	A	K	A	K
Year-round	0.56	0.058	0.30	0.058
Winter	0.56	0.055	0.30	0.048
Summer	0.56	0.066	0.30	0.044

A comparison of the plots for BOD removal and for the remaining SS shows more scatter in the SS data, particularly for the summer periods. The EAFB experimental lagoon data has been identified in these figures to provide a comparison of data from a number of cells in series with the overall data. In all cases the 6 cell operation provided the best performance; however, much of this data was obtained during the first 18 months of the lagoon operation before the aging effect was fully realized. The number of cells in series seemed to have the most pronounced effect on summer SS removals when compared to the overall data. This may be the result of a change in algae species which will be discussed later. The data also indicates that BOD removals are

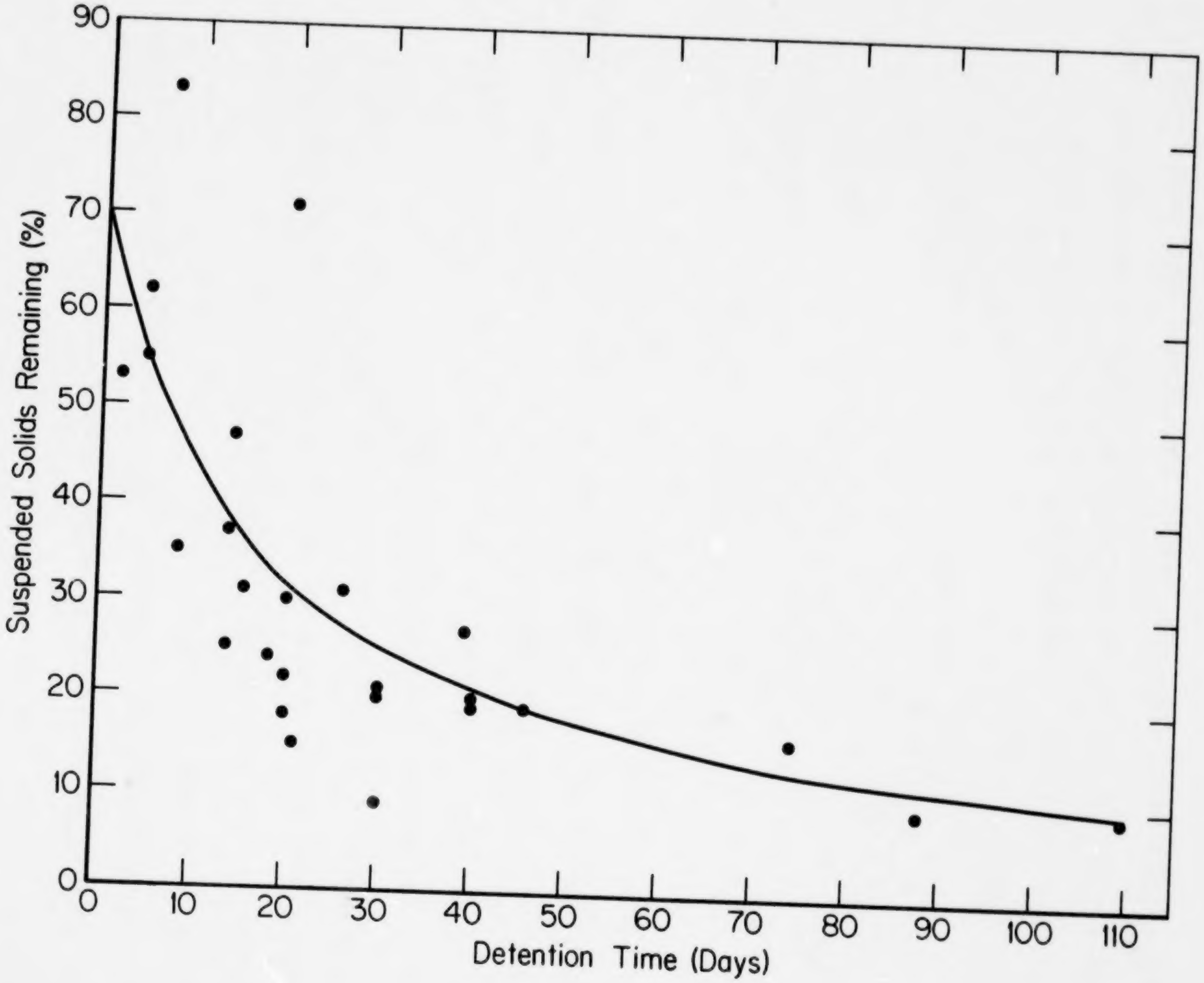

Figure 28. Year-round percent suspended solids remaining vs. detention time.

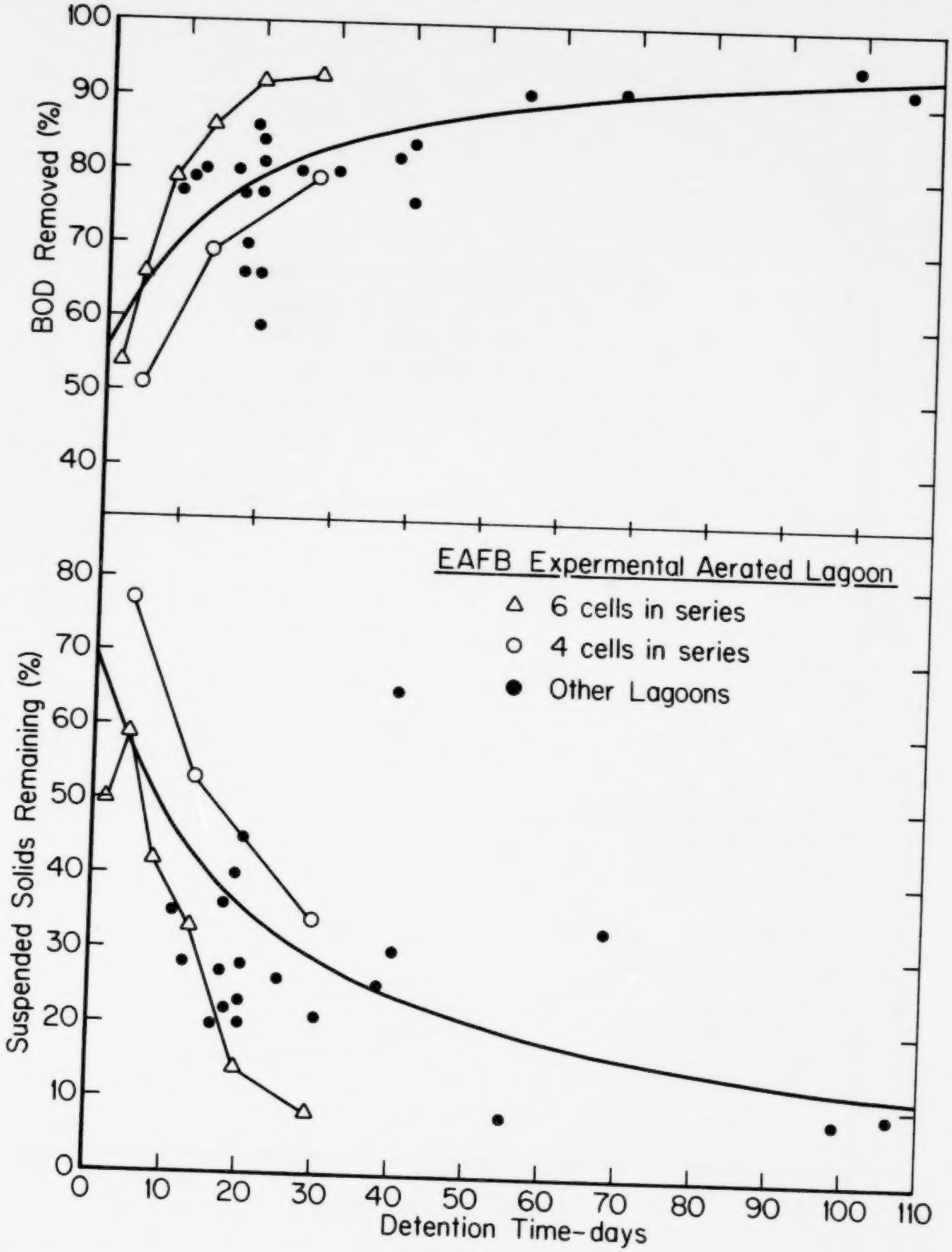

Figure 29. Winter percent BOD removal and percent suspended solids remaining vs. detention time.

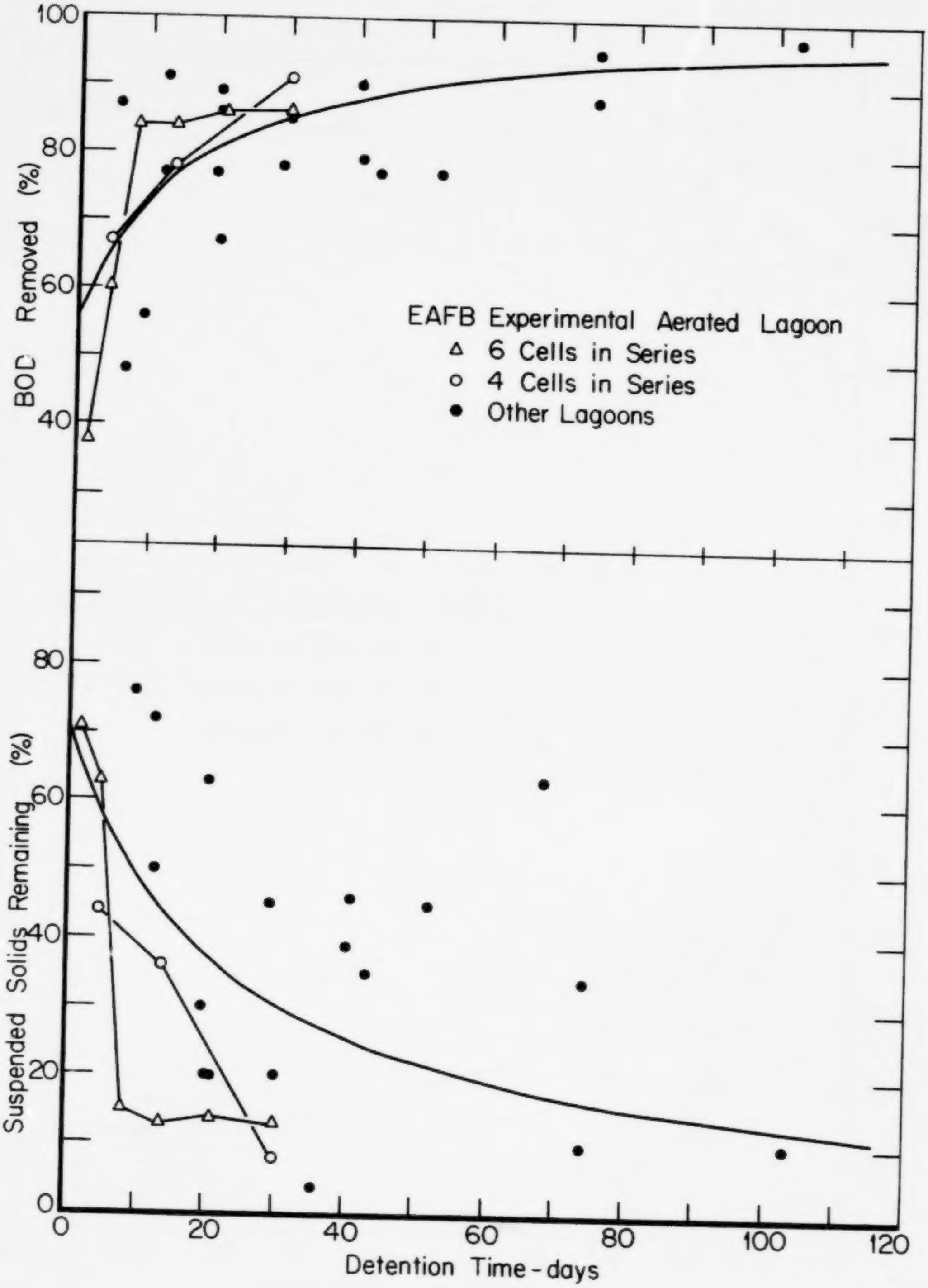

Figure 30. Summer percent BOD removals and percent suspended solids remaining vs. detention time.

improved in the summer although the SS remaining is increased and much more variable because of algae growth.

SOLUBLE BOD REMOVAL

A small fraction of BOD residual does not appear to be removed, even after long detention periods (Eckenfelder and O'Connor, 1961). This has been attributed to an equilibrium between BOD removed and the release back to solution of respiration and auto-oxidation end products. A plot of soluble (filtered through 45 micron filter paper) BOD values shows this residual to be about 10 mg/liter for aerated lagoons with detention times less than 40 days (Figure 31). Reduction of the soluble BOD to 10 mg/liters can occur within 20 days detention time even under extreme winter conditions. After this time, removals of BOD occur through auto-oxidation and sedimentation of solids.

Soluble BOD data was obtained from the EAFB Experimental Lagoon and the Ft. Greely Lagoon under winter conditions and from the Ft. Greely Lagoon under summer conditions. Soluble BOD information was also obtained from a report by Girling et al., (1973) on four aeration basins operated in series. The values shown at zero detention time represent the influent to the lagoon. In the case of the Winnepeg lagoons, the raw waste was fed to a primary cell where the soluble BOD increased before entering the aerated cells.

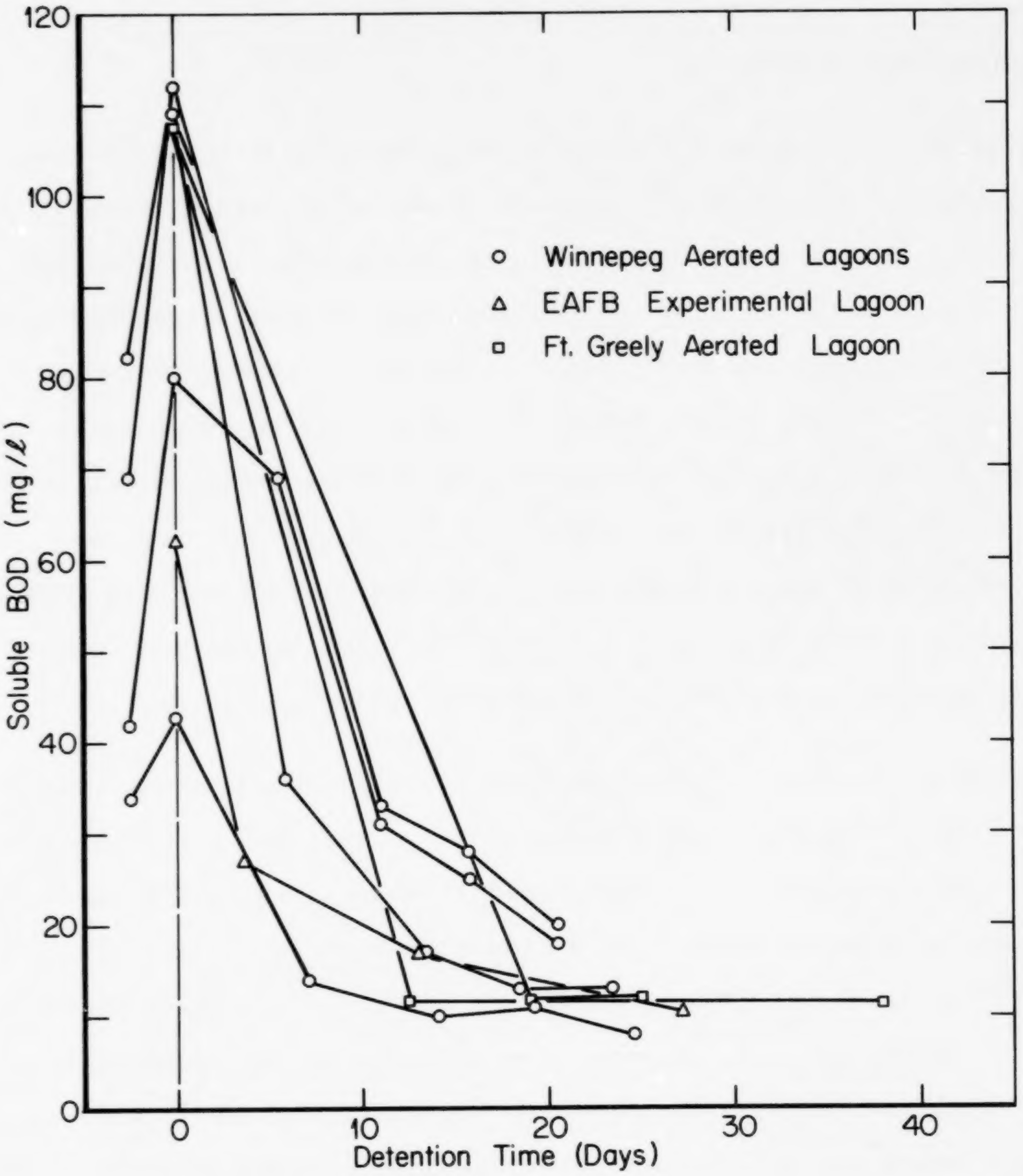

Figure 31. Soluble BOD vs. detention time.

REACTION RATES

Reaction rates are dependent on substrate concentrations and, in lagoon systems, will consequently be dependent on detention times. For a single cell lagoon, increasing the detention time will decrease the overall reaction rate because of the increased substrate dilution. Increases in lagoon detention times result in lesser increases in BOD removal efficiencies (Thirumurthi, 1974). This is an important consideration in determining the removal efficiencies of lagoon cells operated in series using the relationship $1/(1+KT)^n$ since the value of K will decrease with each succeeding cell in series.

After initial oxidation occurs in a biological waste treatment process, the cellular constituents are progressively more difficult to oxidize and the rate declines in a logarithmic manner (Eckenfelder and O'Connor, 1961).

The year-round BOD and SS removal rate coefficients (K) were determined for each cell of the lagoons under consideration and plotted vs loading on log-log paper (Figures 32 and 33). The curves were determined by least squares method. Figures 34 through 37 show plots of winter and summer BOD and SS removal rate coefficients.

A slight curve in the data, particularly for the summer data, appears to exist in the log-log plot. The smaller summer K values

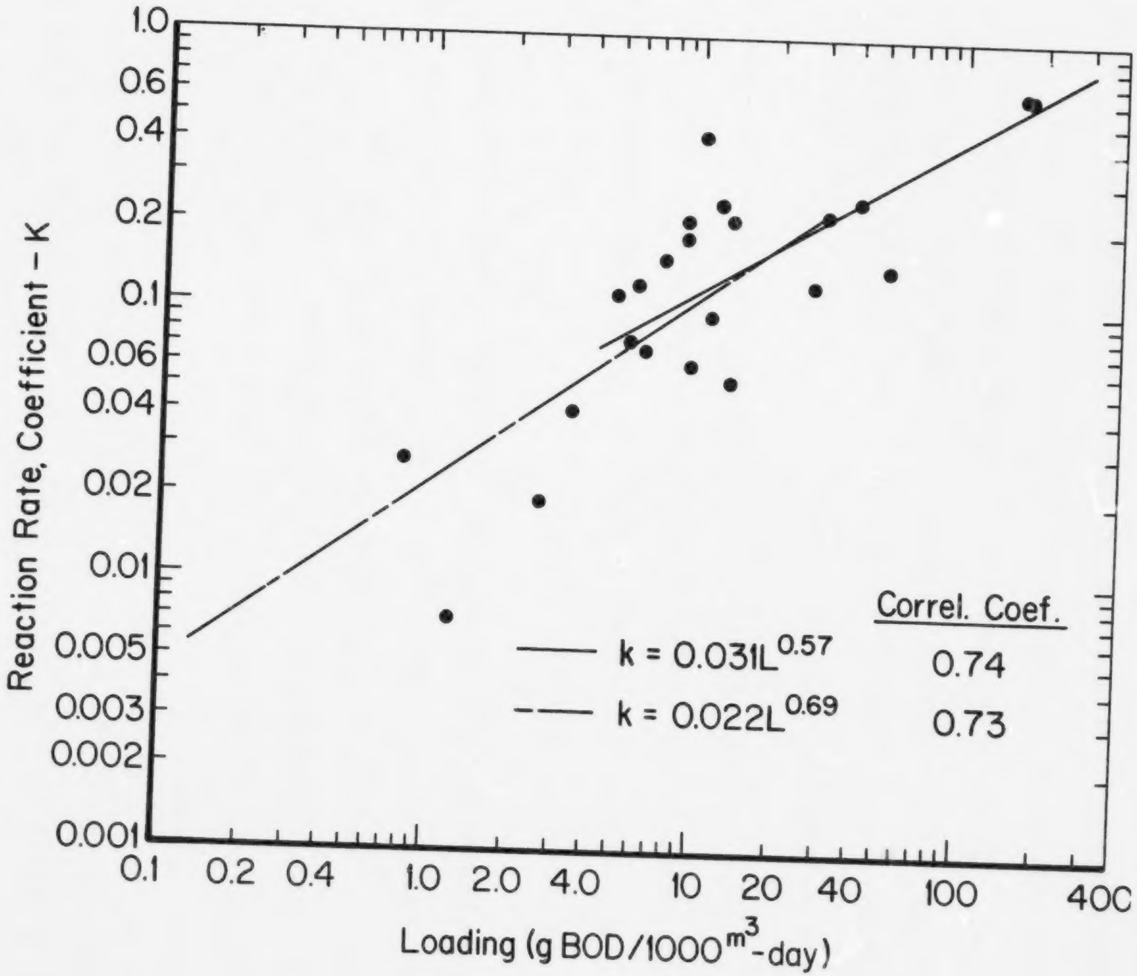

Figure 32. Overall BOD removal rate coefficient vs. loading.

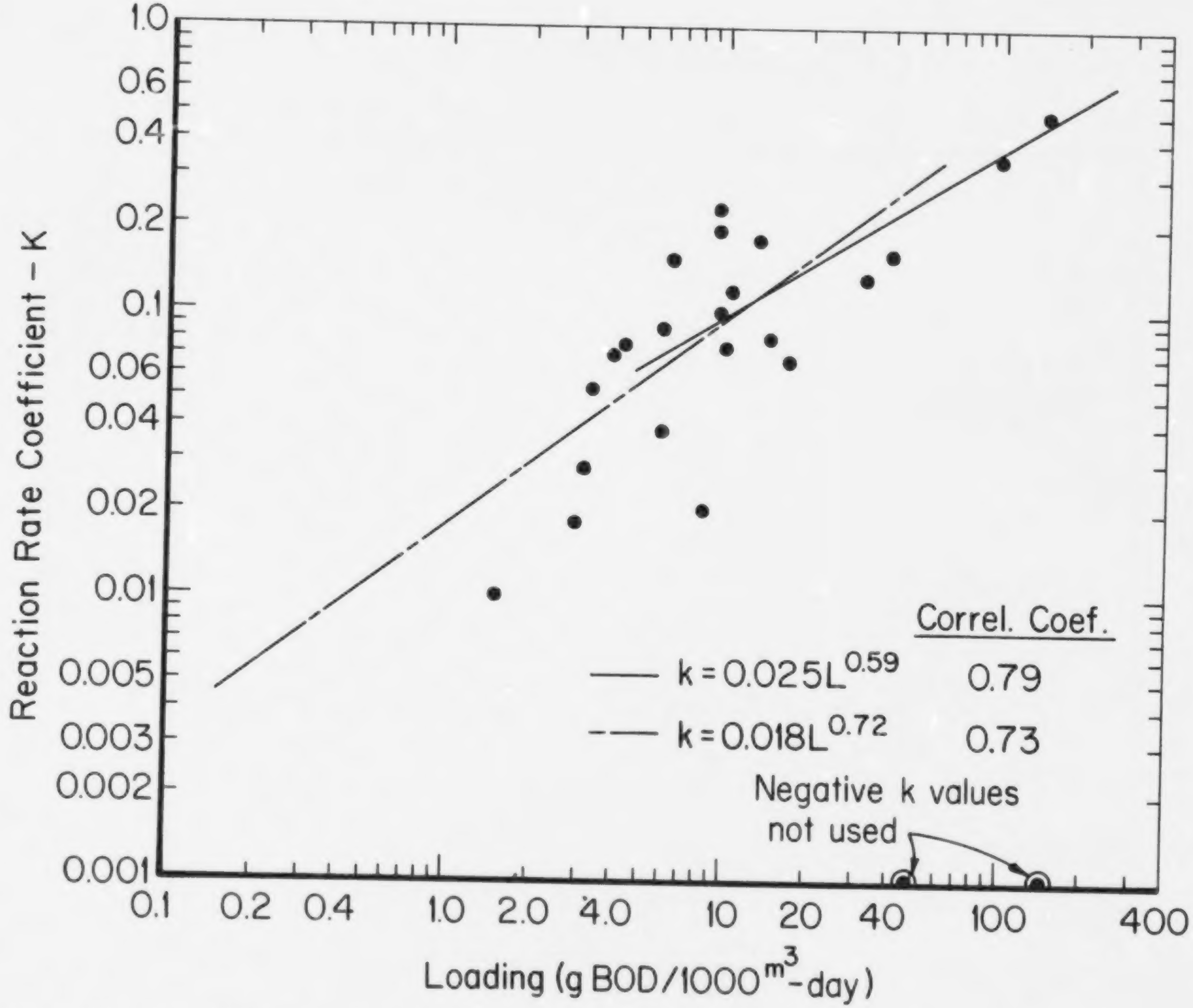

Figure 33. Overall suspended solids removal rate coefficient vs. loading.

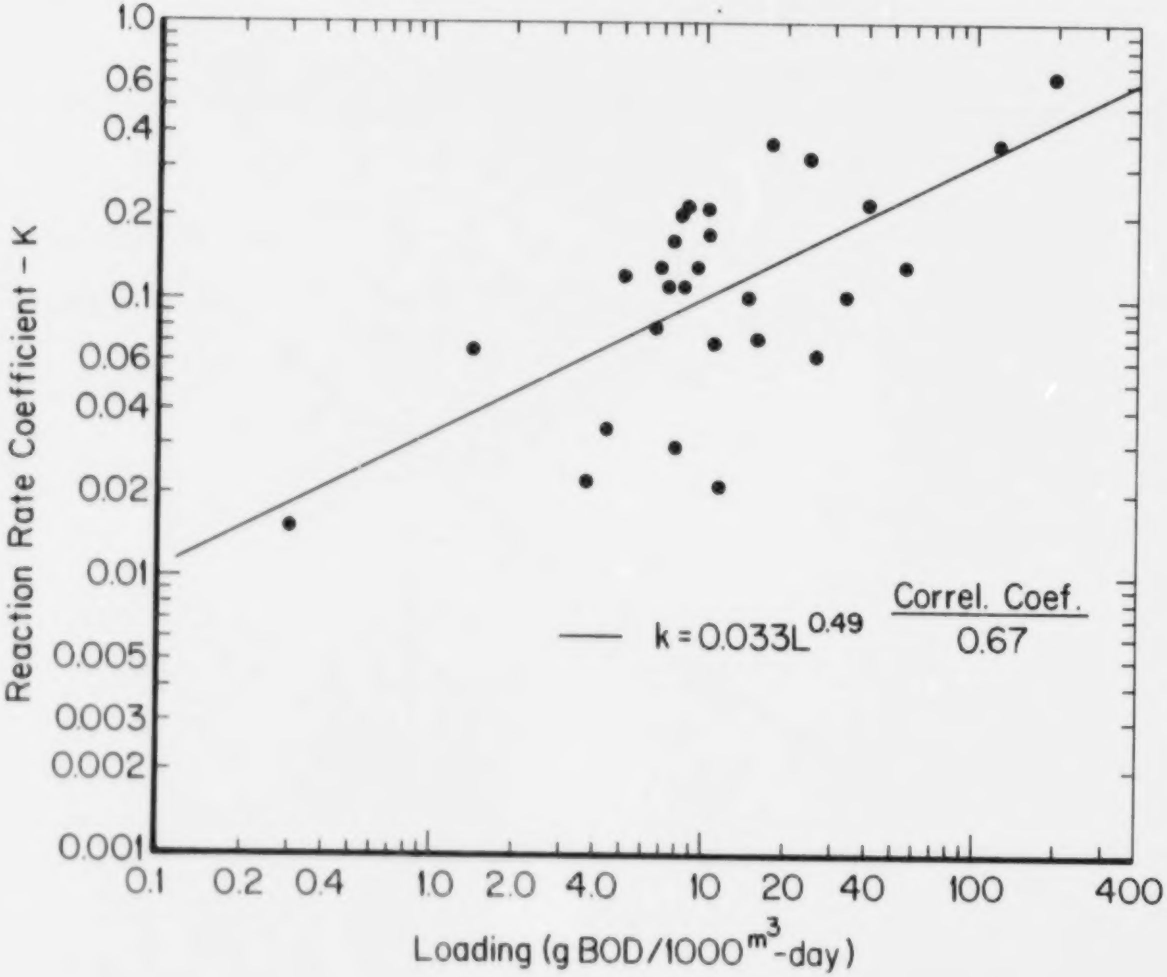

Figure 34. Winter BOD removal rate coefficient vs. loading.

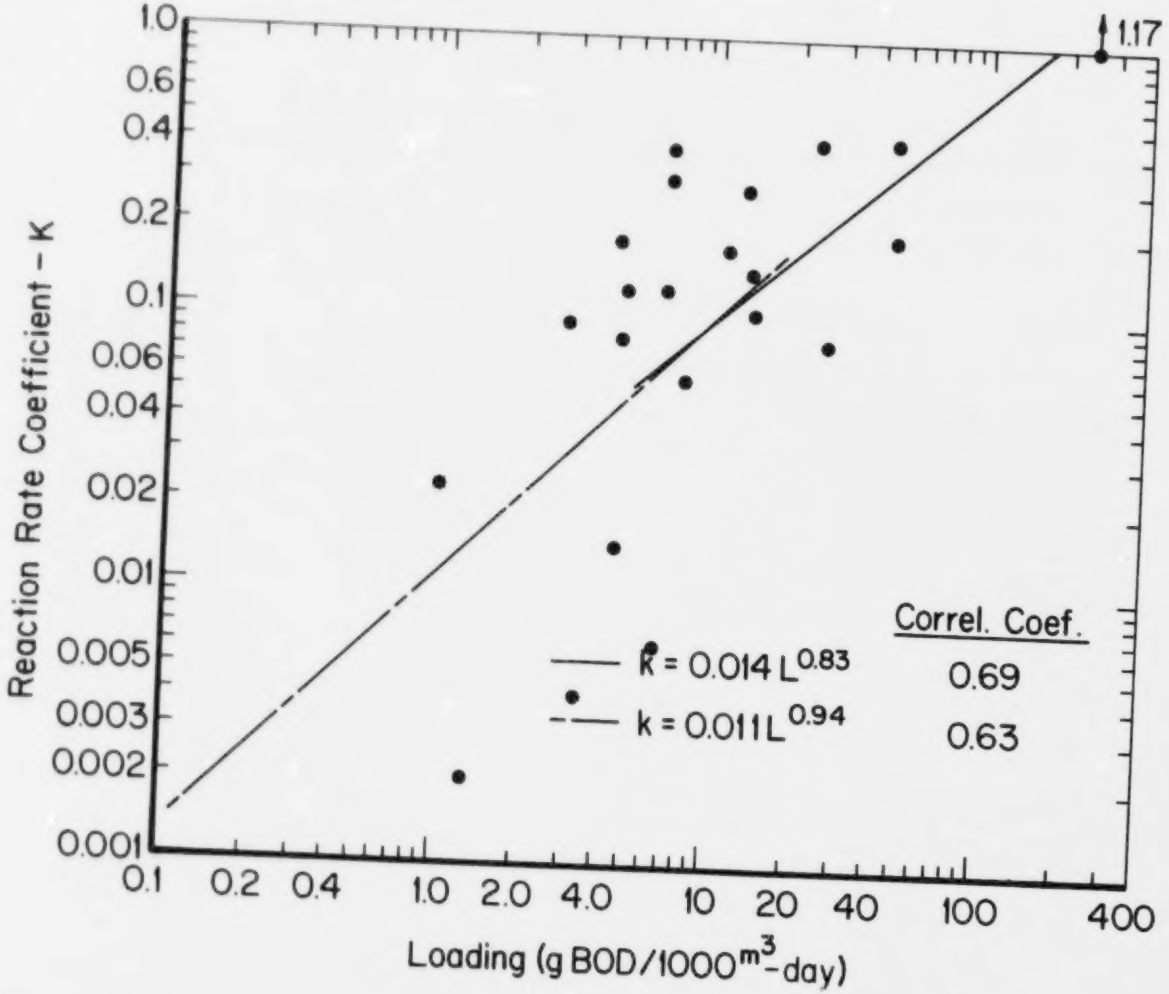

Figure 35. Summer BOD removal rate coefficient vs. loading.

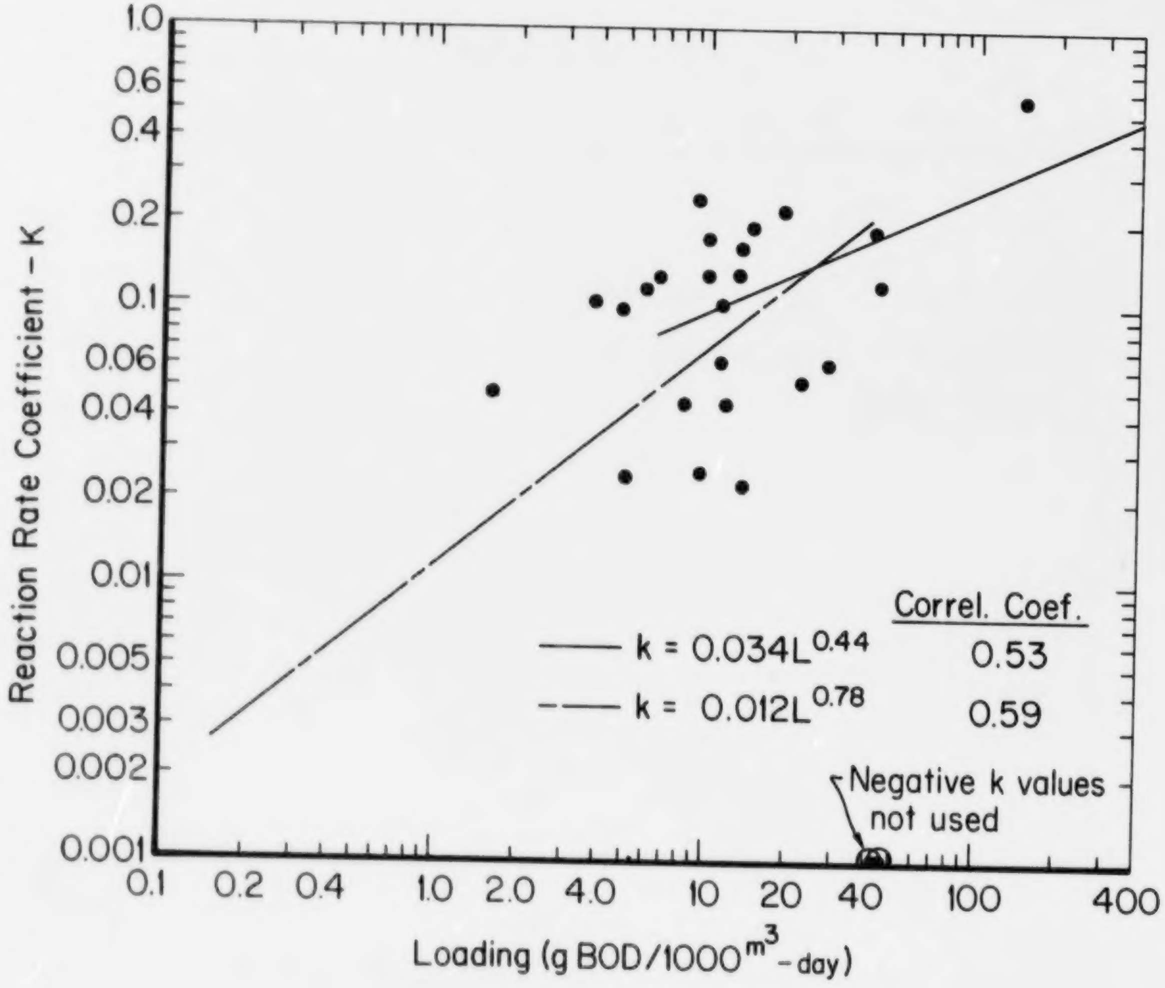

Figure 36. Winter suspended solids removal rate coefficient vs. loading.

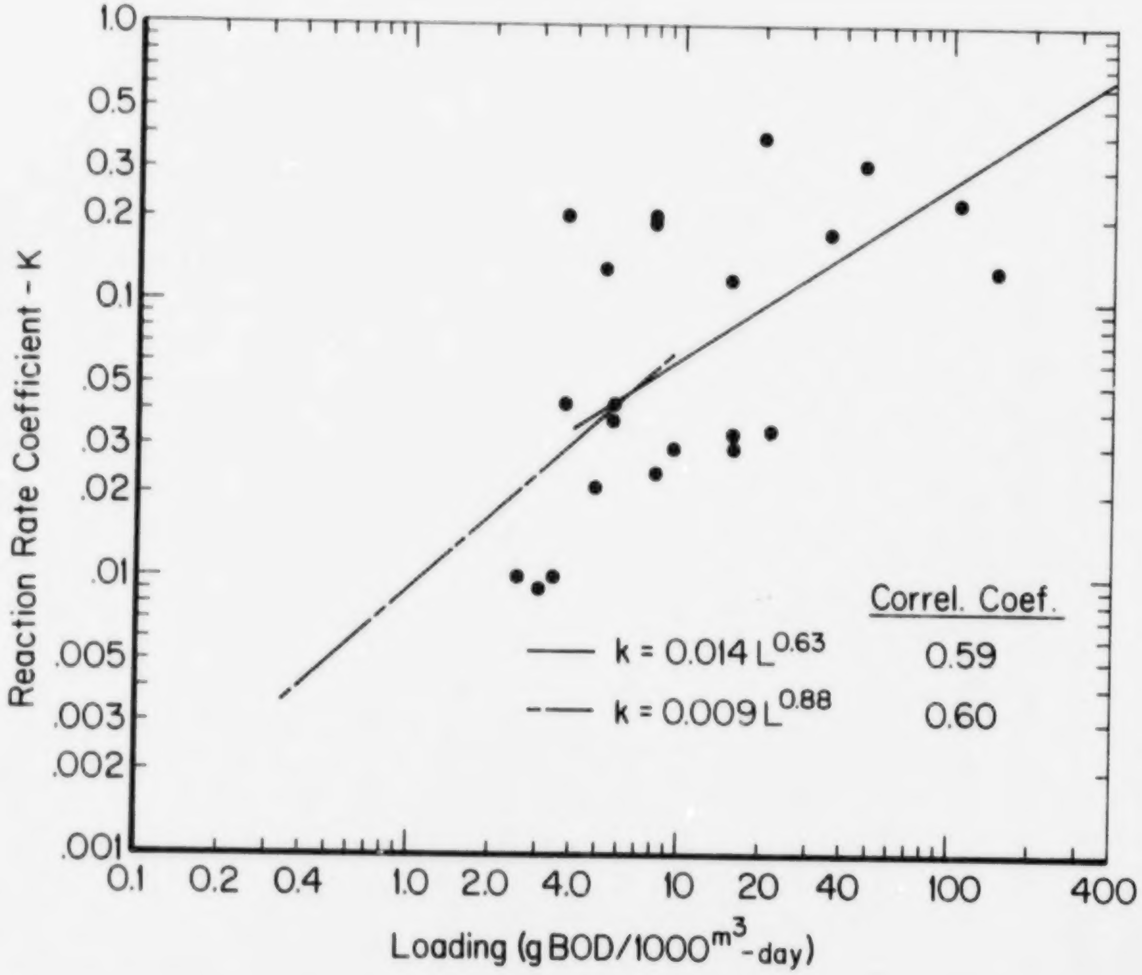

Figure 37. Summer suspended solids removal rate coefficient vs. loading.

at the lower loadings are assumed to be caused by algal growth. The apparent non-linear relationship has been accounted for by fitting two curves for each set of data points, one for lower loadings and one for higher loadings. Some of the data points were not used in determining the curves. These points are indicated on the figures. The curves indicate a relatively rapid increase in removal rates with increasing loading at the lower loadings. This condition makes it more difficult to apply the data to lagoons at the lower loadings, as will be seen in the sample calculations section.

SLUDGE ACCUMULATION

The need for adequate sludge storage in aerated lagoons is made particularly clear by the Eagle River Lagoon experience where effluent quality deterioration was obviously caused by sludge carryover. Lower aerated lagoon performances after the first year of operation are also apparently caused by sludge accumulation. These factors point out the need for incorporating sludge accumulations into aerated lagoon designs.

Following are average sludge analyses for the Northway and Ft. Greely lagoons:

	Total % Solids	% Volatiles	pH	COD(mg/g)
Northway				
Cell 1	12	50	7.1	88
Cell 2	20	29	7.6	46
Ft. Greely				
Cell 1	21	42	5.9	--
Cell 2	52	7	--	--

The Northway sludge exhibited the characteristics of well digested sludge. The pH was relatively high and the sludge had a black appearance and a musty odor. These conditions indicate significant methane fermentation and loss in the form of methane of relatively large amounts of oxygen demand from the system. On the other hand, the Ft. Greely sludge exhibited a low pH and brown, odorous characteristics which indicate production of volatile acids which were not transformed to methane but diffused into the liquid and exerted an oxygen demand. The Ft. Greely sludge pH levels were lower than those reported by Oswald (1968) as optimum for methane formation but near optimum for organic acid formation. pH levels for the Northway sludge were generally in the optimum range for methane formation. It is possible that the poor sludge digestion of the Ft. Greely lagoon occurred because the solids were deposited immediately upon entering the lagoon, probably in a septic condition, so that optimum conditions for organic acid formation were present and perpetuated from the beginning. The lagoon began operation in late fall when the low temperatures would also preclude the growth of methane formers. Oswald (1960) has stated that lagoon bottom sludge can exhibit characteristics of a stuck digester (i.e., high pH which retards methane fermentation) and that overcoming this condition is quite difficult. It follows that startup of lagoons should occur during the warmer summer months or sludge seed containing methane formers, such as from a sludge digester, should be added. Also, if the entering solids are maintained in suspension for a period, undergo some degree of aerobic oxidation and are deposited under the higher pH conditions existing in the lagoon mixed liquor, conditions more conducive to methane formation may be maintained.

The sludge analyses for the Ft. Greely and Northway lagoons are somewhat variable but indicate that decomposition of the sludge occurs year around. Rubel and Gray (1965) also reported % Volatiles of approximately 50 for sludge samples taken in January and February and July and September. This is in agreement with values reported by other investigators.

Very little information is available on rates of sludge accumulation. Sludge volumes obtained from the Northway and Ft. Greely lagoons and information reported by Penman et al., (1970) are shown in Table 21.

Table 21. Sludge Accumulation Summary (ℓ/1000 m^3)

	Cell 1	Cell 2	Total
Northway	935	465	1400
Ft. Greely	620	145	765
Winnepeg			
Air Aqua	1720	380	2100
Air Gun	1880	-	1880

At Winnepeg the high volumes of sludge may be explained by the fact that the information was obtained during the first eighteen months of operation. The Northway and Ft. Greely lagoons were somewhat older when conditions closer to equilibrium existed. This follows from Fair's estimate that it takes over five years to stabilize stream sludge deposits. Using Northway as the most typical situation, it is suggested that for sludge accumulation calculations a value of 1500 liters/1000 m^3 of domestic sewage be used.

ALGAE

The major algae blooms in subarctic lagoons occur around the month of June and are reduced significantly after the sludge turnover, which generally occurred in early July in the lagoons observed. This is illustrated by the Ft. Greely lagoon experience. Major algae growth appears to begin after approximately ten days detention time and follows a typical growth curve as shown by the EAFB experimental aerated lagoon experience.

The 1971 experience with the EAFB experimental aerated lagoon generally agree with statements by Gloyna (1968). Chlorella were dominant during the major algae bloom of June and early July when high sludge decomposition rates and the growth of high energy organisms resulted in presumably high loading. After the sludge turnover and the corresponding reduction in the lagoon loading, Daphnia and filamentous algae became dominant with reduced levels of unicellular organisms resulting in reduced effluent SS levels. A suitable environment for zooplankton growth, as suggested by Dinges (1975), was apparently present.

The correlation of loading and algae blooms is also born out by the Palmer lagoon experience. Summer loading on the total lagoon was 2 g BOD/m^3-day with resultant BOD and SS levels of 6 and 18 mg/liter respectively. Assuming a 55% removal in the aerated cell as for July through September, 1973, the loading on the facultative pond was 1.7 g BOD/m^3-day or 5.1 g BOD/m^2-day.

The advantage of operation with a number of cells in series is illustrated by a comparison of the EAFB experimental lagoon and Ft. Greely lagoon data. The peak chlorophyll values and corresponding SS values obtained were as follows:

	Chlorophyll (m-SPU/m^3)	SS(mg/l)
EAFB Experimental Lagoon	780	86
Ft. Greely Lagoon	1100	141

The higher Ft. Greely values are attributed to the lower number of cells in series. A greater diffusion of incoming raw waste occurred because of the complete mix conditions and the high degree of short-circuiting in that lagoon. The result is a higher level of bacterial activity throughout the lagoon and a correspondingly greater algae growth apparently because of the carbon dioxide generated.

NUTRIENTS

The nutrient data results indicate little change in NH_3-N or T-N levels during winter operations and removals of NH_3-N ranging from 25 to 48% in the summer. T-N removals were less, indicating a transformation of inorganic Nitrogen to the organic form by algae.

Ortho-phosphates and total phosphorus levels increased in almost all cases which would indicate the net annual removals to be zero, assuming the analytical results were accurate. The phosphorus apparently had previously accumulated in the bottom sludge and was being released to the lagoon liquid.

These results are apparently typical of lagoons operated under cold climate conditions.

COLIFORMS

The coliform removal data from the EAFB experimental lagoon and the Harvey, N. Dakota lagoon followed expected patterns (Figure 38). Die off rates were greater during summer periods. Also, for a given detention period, the more cells in series the greater the die off rate. The latter experience is in agreement with results reported by other investigators (Slanetz et al., 1970). The EAFB experimental lagoon achieved 99.98% removal during winter operation with 6 cells in series and during summer operation with 4 cells in series.

The effectiveness of disinfection chambers at the EAFB full scale lagoon and the Eagle River lagoon are shown in Figure 39. Attempts to correlate coliform counts with the product of contact time and chlorine residual were not successful and better results were obtained plotting coliform levels vs contact time. The data from the Eagle River and EAFB lagoons indicate little difference in disinfection effectiveness during winter and summer operations. This would seem to indicate the summer algae production

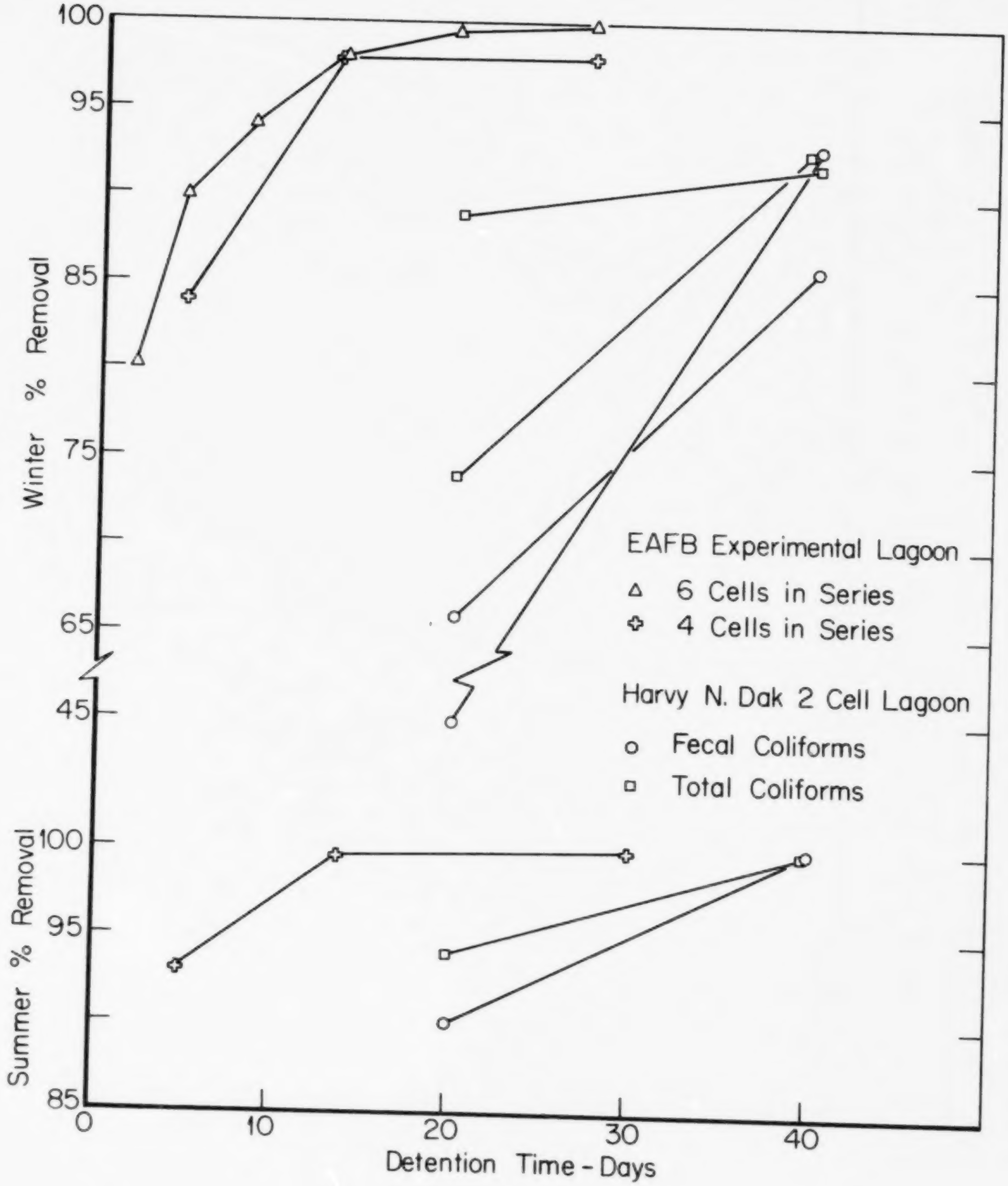

Figure 38. Aerated lagoon coliform removals.

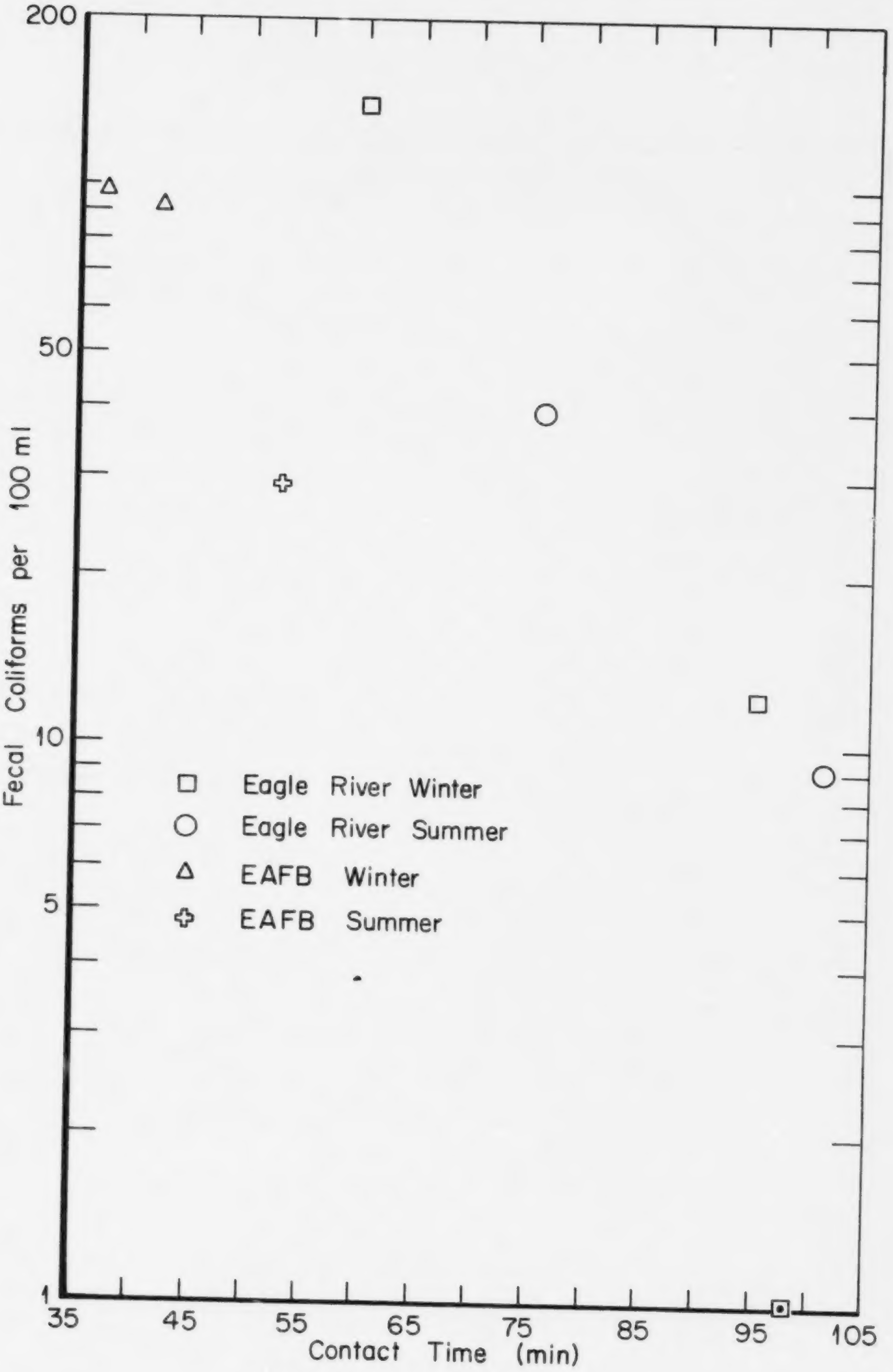

Figure 39. Eagle River and EAFB full scale lagoons fecal coliform vs. chlorination contact time.

results in disinfection rates similar to those during cold temperature operations in winter.

The fecal coliform data also supports the contention that monitoring chlorine residual as a means of determining disinfection effectiveness will not be satisfactory. The EAFB lagoon effluent coliforms were reduced at lower contact times and lower chlorine residuals than the Eagle River Lagoon effluent coliforms.

AERATION SYSTEMS

Although fine bubble diffusers have performed successfully in aerated lagoons for a number of years, clogging is obviously an inherent characteristic in their operation. The clogging can cause maintenance problems, particularly in small installations where the operator may have many other duties to attend to aside from operation of the waste treatment system. Some problems which have occurred include blower damage, breaks in plastic piping, blowing out of the ceramic diffusers, etc. Many problems have also occurred with the plastic pipe in the Eagle River lagoon which were not associated with high system pressure.

In most cases, cleaning of fine bubble diffusers is required with greater frequency than recommended by the manufacturer. Perforated tubing cleaning is generally required monthly to maintain desired blower discharge pressures. Cleaning of the porous ceramic diffusers may be required once per year, based on the limited information available.

Obstruction of the fine bubble aerators may occur internally during shutdown of the blowers which allows wastewater and suspended matter to enter the aeration system through the diffusers and leaks in the piping. Clogging can occur through obstruction by particulate matter or through an inability to force water out of the system through the diffusers. Removal of the material from the tubing may be accomplished by installation of bleed lines and "rocking" the system as at the Palmer Lagoon. Particulate matter in the air supply will also cause internal clogging although this has not been a problem at most sites in Alaska.

External restrictions can be caused by calcium carbonate deposits from hard water or organic slime growths over the diffusers. Clogging of the perforated tubing, which is designed to lie on the lagoon bottom, may also occur from sludge deposits on top of the tubing. Clogging of the porous ceramic diffusers can occur during blower shutdowns due to lint and hair collecting on the diffusers and in the pores.

Routine cleaning of both types of fine bubble diffusers is generally accomplished with hydrochloric acid fed to the aeration system and forced through the diffusers at approximately 1.4 kg/cm^2 or by applying hydrogen chloride gas to the system while the blowers are in operation. The latter method requires the greatest care because of the toxic and corrosive nature of the material. Amounts of material used for cleaning have varied considerably. In the case of perforated tubing, quantities of 3.7 and 1.6 g/m of hydrochloric acid and hydrogen chloride gas, respectively, appear to be adequate if a monthly cleaning schedule is adhered to. Sufficient information was not available on the porous diffusers to determine the amount of cleaning material required.

In a number of cases, more extreme cleaning methods have been necessary. These have included draining the lagoon to a level which would permit access to the diffusers and hand cleaning with the blowers in operation.

Air Gun aerators have also been utilized in lagoons for a number of years. The main operating problem has been blocking by rags, and whether this problem has been corrected is not known.

AERATION DIFFUSERS

Information has been presented which indicates the coarse bubble diffusers can provide an attractive alternative for aeration in lagoons, particularly in smaller systems. The K_La values obtained from the Ft. Greely coarse bubble diffuser studies correlate well with those obtained for the same diffuser in a large scale activated sludge aeration tank model. The data shows that coarse bubble aeration systems for lagoons can be designed based on oxygenation efficiencies published in the literature or supplied by diffuser manufacturers. The oxygenation efficiencies should be obtained from large scale test tanks rather than small columns, however, for reasonable accuracy. The data also indicates the $K_L a$ value can be predicted for coarse bubble diffusers in lagoons using the equation developed by Eckenfelder and information presented in the literature (Eckenfelder and O'Connor, 1961; Eckenfelder and Ford, 1968).

Studies have shown that increased aeration tank widths decrease oxygenation efficiencies to a certain minimum level but that spreading the diffusers out over the tank bottom increases oxygenation efficiencies. The large width to depth ratio of lagoons will decrease diffuser efficiencies to some extent, probably 2 to 3 percent efficiency for coarse bubble diffusers based on studies mentioned previously (Bewtra and Nicholas, 1964). Efficiencies for a given diffuser can be maximized, however, by adequate spacing to minimize interfering bubble patterns.

Although the fine bubble diffusers' oxygenation efficiencies are greater, the diffusers are not necessarily more economical. The data presented in Table 19 indicates approximately 0.79-0.84 kg transferred/kWh for the coarse bubble diffusers, as opposed to approximately 0.6 kg O_2 transferred/kWh for the fine bubble diffusers under generally clogged conditions. Assuming for the Ft.

Greely lagoon that 190 l/s at 0.35 kg/sq cm would be required for a coarse bubble diffuser system while 142 l/s at an average of 0.46 kg/sq cm would be required for a fine bubble diffuser system under normal conditions, the increased cost for the coarse bubble system would be $78/year greater at 2 cents/kWh. However, if cleaning were required monthly for the fine bubble diffusers, assuming 4 man hours per cleaning at $10/hour and $8 material cost, maintenance cost would be $576/year or a net $498/year greater cost for the fine bubble diffuser system. These differences will increase if hand cleaning is necessary and decrease if higher power costs exist. Based on the above, it appears that operation and maintenance costs for fine bubble diffusers may be equal to or greater than the costs for coarse bubble diffusers if significant clogging occurs.

One aspect of aeration system design which must be considered in some areas is ice fog generation. Visual observations at Ft. Greely indicated open water over all four coarse bubble diffuser clusters throughout the winter period. These open areas decreased in size as the air temperature decreased and would almost completely ice over above the Aer-O-Flo clusters at -40°C. The open area above the Shearfuser cluster near the influent always remained larger, shrinking to about 7.5 m in diameter at -40°C. Significant ice fog generation seemed to occur only over this cluster. Ice fog blankets were not observed around the lagoon as the ice fog formed was either not enough to become a nuisance or dissipated rapidly. It should be noted that the influent sewage temperatures to this lagoon range around 20°C even in winter and that lower influent temperatures would reduce ice fog generation. During the colder period of the year, the perforated tubing side of the lagoon was completely ice covered and no ice fog was observed.

Although no attempts at heat balance calculations have been made, an observation is that greater heat losses occur over diffusers with larger air flows or greater turbulence because of the larger open areas maintained. This greater heat loss through the open area is compensated for by increased ice thickness, or lesser heat losses, through the rest of the lagoon. Thus, a fine bubble diffuser lagoon may have a thin ice cover over the total surface while a coarse bubble lagoon may have thicker ice over less than 100 percent of the lagoon due to greater concentration of air flows. Where ice fog may be a problem or extensive freezing is anticipated, diffusers should be selected which require less air flow per diffuser and will permit greater dispersion of the air pattern. Smaller clusters of diffusers should also be used. As indicated previously, oxygenation efficiencies will not be significantly affected as transfer rates are independent of diffuser spacing.

LAGOON DESIGN AND UPGRADING

DISCUSSION

A comparison of data from the Eagle River and Palmer lagoons illustrates the importance of proper design. Second year overall series operation data from the Eagle River lagoon and data for the period May 1, 1974 through April 30, 1975 for the Palmer lagoon were plotted on probability paper. The percentage of BOD and SS analyses that exceeded 30 mg/l and 70 mg/l were as follows:

Lagoon	30 mg BOD	30 mg SS	70 mg SS	Loading g BOD/m^3-day
Eagle R.	55	70	30	10.2
Palmer	10	4	<1	1.7

The Eagle River lagoon performance, although poor, is the more typical of present subarctic lagoons. The lagoon is overloaded, has inadequate sludge storage and has been plagued with aeration system problems which have contributed to the poor performance results. The Palmer lagoon, on the other hand, while not an ideal design, has a considerable reserve capacity. Some problems have been encountered with the fine bubble aeration system.

These problems have been minimized by close attention to the lagoon and some innovative maintenance provisions such as installation of bleed off piping at the ends of the main air headers to blow water out of the tubing diffusers.

In the design or upgrading of cold climate lagoon systems, the following objectives should be kept in mind:

1. As in any biological treatment system, conversion of dissolved and colloidal organic material into suspended solids which can be removed by sedimentation is essential. Soluble BOD can be reduced to around 10 mg/l in relatively short periods (<20 days) even at 0°C liquid temperatures.

2. A high proportion (25-50%) of the first cell aeration should be concentrated at the lagoon influent to prevent buildup of sludge under septic conditions.

3. Adequate sludge storage must be provided in the first sections of the lagoon so that adequate treatment of the organic acids etc., given off during summer fermentation, occurs before the effluent is discharged. Accumulation of approximately 1500 liters of sludge per 1000 m^3 of influent should be allowed for.

4. Lagoon cells should be provided in series to reduce short-circuiting due to complete mix conditions and other causes. For lagoons of a given detention time, the numbers of bacteria and indicator organisms are reduced further in multicell series systems than in single cell lagoons.

5. A polishing or maturation pond should be provided as the last cell in series to allow sedimentation of any settleable solids and consumption of unicellular algae by higher organisms. Care should be taken to provide an optimum environment for zooplankton growth. Loading on the polishing pond should be limited to 1 - 1.5 g BOD/m^3-day or 4 - 5 g BOD/m^2-day.

A suggested lagoon arrangement is shown in Figure 40 and sample design calculations follow. A short detention cell is created at the influent structure by constructing a baffle. Heavy aeration in this cell will keep more solids in suspension and allow greater aerobic oxidation before the solids are deposited. Also, the soluble BOD will undergo greater reduction with higher VSS levels.

Sludge storage is provided over the total bottom area of the aerated cells in order to avoid excessively deep sludge deposits. Colder sludge temperatures can be expected with deeper deposits which will result in reduced decomposition rates. The aerators are shown elevated and also in a configuration which will allow sludge removal.

Placing of the aerators in a straight line parallel to the flow and along the full width of the lagoon will also aid in reducing short-circuiting. A rolling motion of the fluid will be established in the section between each line of aerators which will promote mixing of incoming waste in that section before the

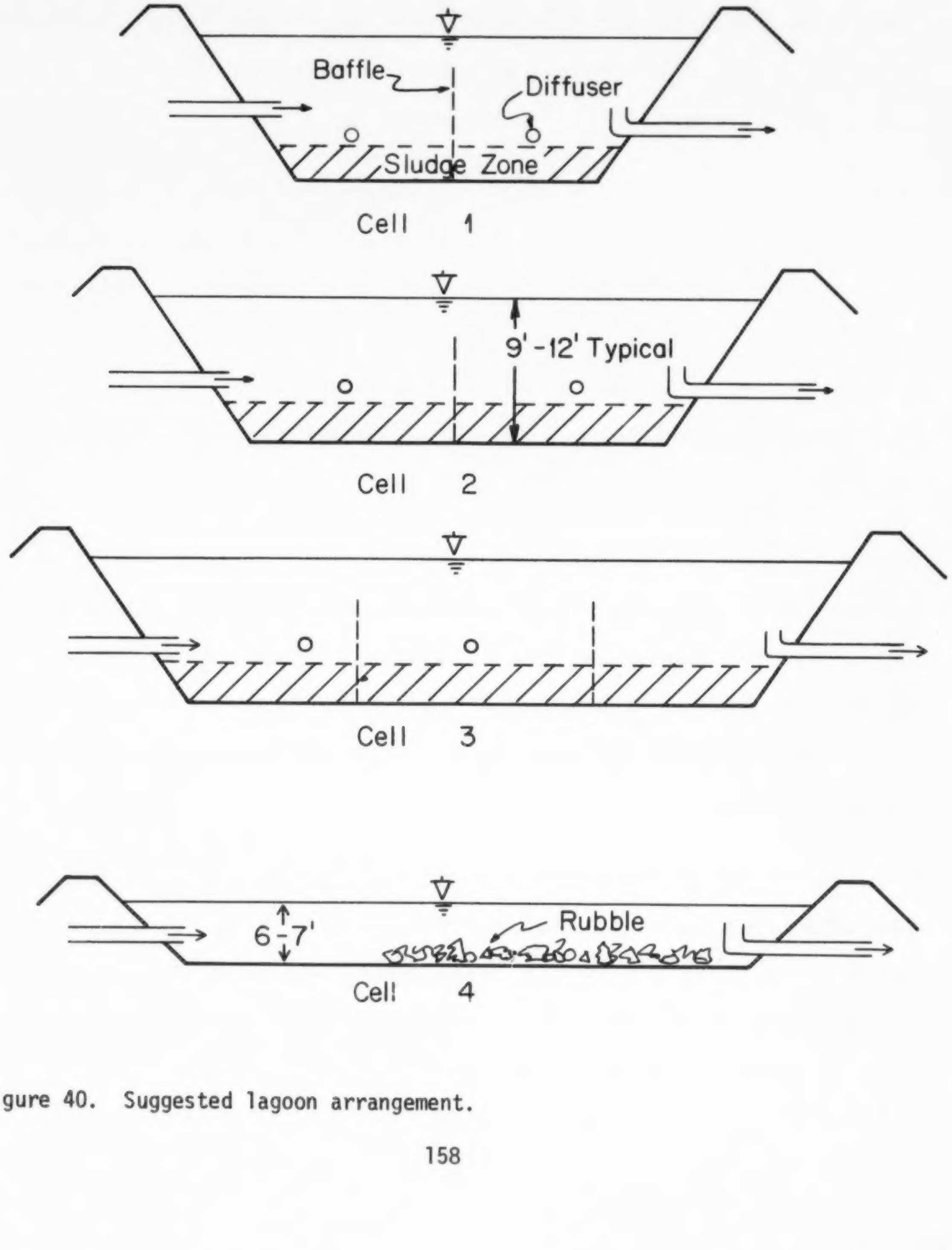
Baffle
Diffuser
Sludge Zone
Cell 1
9'-12' Typical
Cell 2
Cell 3
6-7'
Rubble
Cell 4

Figure 40. Suggested lagoon arrangement.

waste moves to the next section. The aeration pattern will tend to create a barrier to complete mixing throughout the pond and thereby reduce short-circuiting. Short-circuiting can be further reduced by the strategic placement of baffles which do not extend to the pond surface but which serve as an additional barrier to complete mix conditions.

A polishing pond is provided to permit sedimentation of any remaining settleable solids during winter operation and to provide for algae reduction during summer operation. The pond should provide a suitable environment for macro-organisms such as Daphnia which prey on the algae. If aeration is provided it must be gentle and not promote excessive agitation. Adequate dilution must be provided to reduce organic concentrations and to curb algae blooms which raise pH. Rubble may be included in order to provide a surface for the growth of the macro-organisms.

Some precautions regarding freezing must be considered when using a lagoon arrangement as suggested in Figure 40. In the design of multi-cell systems, special care must be taken to avoid freezing problems when transferring from one cell to another. The application of adequate insulation and/or the addition of heat (heat tapes e.g.) at the transfer points are necessary in Arctic and Subarctic areas (Lynn Wallace, personal communication, 1976). Also, if the baffles are designed to extend into the freezing zone, special baffle designs must be provided to prevent ice damage.

Possible alternatives to the above scheme include long term storage with discharge once or twice per year at appropriate receiving water conditions (Pierce, 1974); phase isolation as practiced in California (Hiatt, 1975); and discharge to natural lakes or swampland as described by Grainge et al., (1972).

All of the above considerations should be examined in the design of new lagoons or upgraded lagoons.

SAMPLE CALCULATIONS

It has been shown that the reaction coefficient in the complete mix equation is related to loading by the following equation (See Figures 32 and 33):

(1) $K = aL^b$

where K = reaction coefficient

L = loading (g BOD/m^3-day)

a&b = constants

Also:

(2) $L = S_o/t$

where S_o = influent BOD (mg/l)

t = detention time (days)

By substitution into the complete mix equation it can be shown that:

(3)

$$t = \left[\frac{\frac{S_o}{S_e} - 1}{a \cdot S_o^{\,b}} \right]^{1/(1-b)}$$

Using Figures 32 through 37 and the above relationships, the performance of a lagoon may be predicted.

As an example, winter BOD removals have been predicted for a lagoon as follows:

Assumptions:

S_o (Influent BOD) = 250 mg/l

S_e (Effluent BOD) = 20 mg/l

SS_o (Influent Suspended Solids) = 200 mg/l

SS_e (Effluent Suspended Solids) = 20 mg/l (winter)

SS_e (Effluent Suspended Solids) = 60 mg/l (summer)

Cell 1 DT = 10 days

Cell 2 DT = 15 days

Cell 3 DT = 15 days

Cell 4 DT = ?

Cell 1

$L = S_o/T = 250/10 = 25$

From Figure 34, K = 0.15

$S_e = S_o/(1 + Kt) = 250/(1 + 0.15 \times 10) = 100$ mg/l

Cell 2

$L = 100/15 = 6.7$

From Figure 34, $K = 0.08$

$S_e = 100/(1 + 0.08 \times 15) = 45.5$ mg/l

Cell 3

$L = 45.5/15 = 3.0$

From Figure 34, $K = 0.056$

$S_e = 45.5/(1 + 0.056 \times 15) = 24.7$

Cell 4

Using equation (3)

$$t = \left[\frac{24.7/20 - 1}{0.033 \times 24.7^{0.49}}\right]^{1/(1-0.49)}$$

$$t = (0.24/0.16)^{1.96}$$

$$t = 2.2 \text{ days}$$

Total detention time required = 42 days. Using the same approach for summer BOD removals, the performance would be as follows:

Cell 1

$L = 250/10 = 25$

From Figure 35, $K = .20$

$S_e = 250/(1 + 0.20 \times 10) = 83.3$

Cell 2

$L = 83.3/15 = 5.6$

From Figure 35, $K = 0.056$

$S_e = 83.3/(1 + 0.056 \times 15) = 45.3$

Cell 3

$L = 45.3/15 = 3.0$

From Figure 35, $K = 0.030$

$S_e = 45.3/(1 + 0.030 \times 15) = 31.2$

Cell 4

Using Equation (3)

$$t = \left[\frac{31.2/20 - 1}{0.011 \times 31.2^{0.94}}\right]^{1/(1-0.94)}$$

$$= (0.56/0.28)^{16.7} = \text{unrealistically high}$$

Because of the rapid decline of the K values at low loadings, the last cell size is unrealistically high. Try 5 cells in series:

Cells 1 - 4 DT = 10 days

Cell 1

$L = 250/10 = 25$

$K = 0.20$

$S_e = 83.3$

Cell 2

$L = 83.3/10 = 8.3$

$K = 0.08$

$S_e = 83.3/(1 + 0.08 \times 10) = 46.3$

Cell 3

$L = 46/10 = 4.6$

$K = 0.046$

$S_e = 46/(1 + 0.05 \times 10) = 31.5$

Cell 4

$L = 31.5/10 = 3.2$

$K = 0.033$

$S_e = 31.5/(1 + 0.033 \times 10) = 23.7$

Cell 5

Using Equation (3)

$$t = \left[\frac{23.7/20 - 1}{0.011 \times 23.7^{0.94}}\right]^{1/(1-0.94)}$$

$$(.018/0.22)^{16.7} = 0.05$$

Again, because of the rapid decline in K values at lower loadings, the last cell size obtained with equation (3) is not realistic. The calculations do indicate that 5 cells total with the first 4 cells sized at 10 days detention time each will be adequate. The last cell should be sized using the loading factor of 1.5g BOD/m^3-day.

$t = S_o/1.5 = 23.7/1.5 = 16$ days

Total detention time = 56 days

Using the 5 cells in series, the winter BOD removals would be as follows using Figure 34:

Cell 1

$L = 250/10 = 25$

From Figure 34, $K = 0.15$

$S_e = 250/(1 + 0.15 \times 10) = 100$

Cell 2

$L = 100/10 = 10$

$K = 0.10$

$S_e = 100/(1 + 0.10 \times 10) = 50$

Cell 3

$L = 50/10 = 5$

$K = 0.07$

$S_e = 50/(1 + 0.07 \times 10) = 29.4$

Cell 4

$L = 29.4/10 = 2.9$

$K = 0.055$

$S_e = 29.4/(1 + 0.055 \times 10) = 19.0$

Cell 5

$L = 19.0/16 = 1.2$

$K = 0.036$

$S_e = 19.0/(1 + 0.036 \times 16) = 12$

Summer suspended solids removals are estimated as follows using Figure 37:

Cell 1

$L = 200/10 = 20$

$K = 0.095$

$S_e = 200/(1 + 0.095 \times 10) = 102.6$

Cell 2

$L = 102.6/10 = 10.3$

$K = 0.063$

$S_e = 102.6/(1 + 0.063 \times 10) = 62.9$

Cell 3

$L = 62.9/10 = 6.3$

$K = 0.046$

$S_e = 62.9/(1 + 0.046 \times 10) = 43.1$

Cell 4

$L = 43.1/10 = 4.3$

$K = 0.033$

$S_e = 43.1/(1 + 0.033 \times 10) = 32.4$

Cell 5

$L = 3.2$

$K = 0.025$

$S_e = 32.4/(1 + 0.025 \times 16) = 23.14$

Winter suspended solids removals using Figure 36 would be as follows:

Cell 1

$L = 200/10 = 20$

$K = 0.12$

$S_e = 200/(1 + 0.12 \times 10) = 90.9$

Cell 2

$L = 90.9/10 = 9.1$

$K = 0.065$

$S_e = 90.9/(1 + 0.065 \times 10) = 55.1$

Cell 3

$L = 55.1/10 = 5.5$

$K = 0.044$

$S_e = 55.1/(1 + 0.044 \times 10) = 38.3$

Cell 4

$L = 38.3/10 = 3.8$

$K = 0.032$

$S_e = 38.3/(1 + 0.032 \times 10) = 29.0$

Cell 5

$L = 29.0/16 = 1.8$

$K = 0.018$

$S_e = 29.0/(1 + 0.018 \times 16) = 22.5$

Since the effluent suspended solids are above 20 mg/l, use equation (3) to recalculate the cell 5 detention time requirement. Using equation (3)

$$t = \left[\frac{29.0/20 - 1}{0.012 \times 29.0^{0.78}}\right]^{1/(1-0.78)}$$

$$t = (0.45/0.17)^{4.55}$$

$$= 83.9 \text{ days}$$

Again, the detention time for cell 5 is unrealistically high. In order to obtain winter suspended solids levels of 20 mg/l or less, an additional short detention time cell should be added or the size of some of the first four cells should be increased.

The advantage of using a number of cells in series is shown in Figure 41. The winter BOD removal efficiency of the 5 cell lagoon derived above is compared to the BOD removal efficiency of a 3 cell lagoon determined in the same manner. The 5 cell lagoon with shorter detention times in the first cells obviously

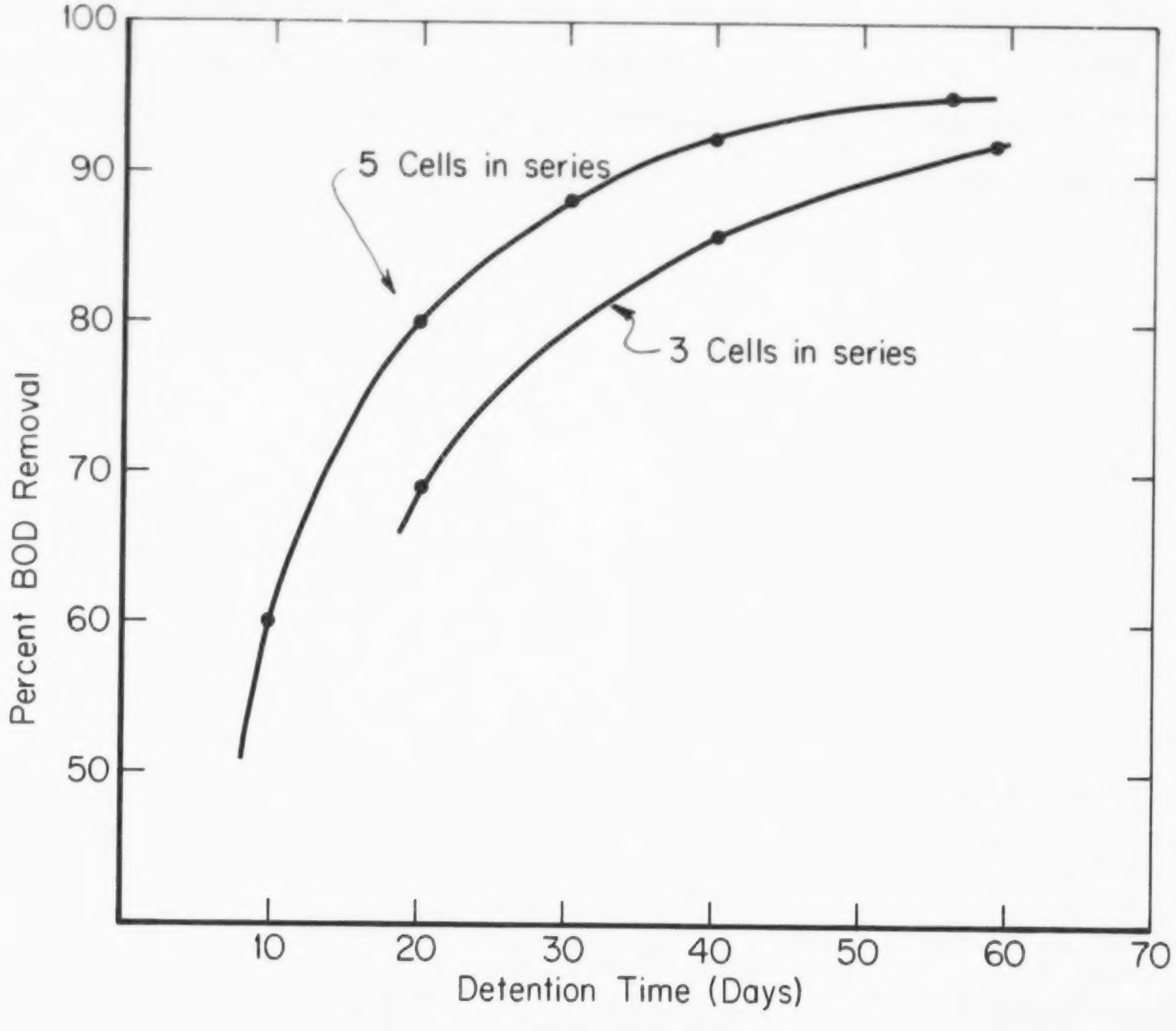

Figure 41. Effect of cells in series on detention time.

will result in more efficient treatment. A lagoon designed by the procedures outlined above can be expected to meet 30 mg/l BOD_5 and 30 mg/l SS standards in the effluent over 90% of the time. This conclusion is based in part on the performance of the Palmer lagoon (see Figure 22).

The use of a very short detention time per cell (one day for example) will result in higher loadings and correspondingly higher removals when predicting performance from Figures 32 through 37. This approach is not recommended, however. Unrealistically high removal predictions may be the result.

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